CENBG

LAB

Mars environment simulations for traces of life detection

Geant4 Space Users' Workshop 2008

Tokyo, 13th February 2008 Aurélie LE POSTOLLEC Aurélie Le Postollec

13th February 2008

Context

- Search for extraterrestrial life: new challenge
- Mars: special exobiologic interest for upcoming missions (ESA-EXOMARS, NASA-PHOENIX…)
- New tools, miniaturized, sensitive
  - ➡ biochip development
- Resistance of these new tools to space conditions?
- Radiation : critical issue
- Need for simulations to define relevant experiment parameters
- BiOMAS (Biochip for Organic Matter Analysis in Space) project: funded by the French Space Agency (CNES)
  - BiOMAS - ARCoR (Antibodies Resistance to Cosmic Radiation)

Biochip

- Definition

  → Miniaturized device composed of sensitive biological molecules (ligands) fixed on a slide.

  → Detection of organic molecules (biomarkers) that could sign life.
- Principle

Support
+
Ligands in solution ⟶

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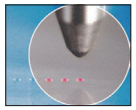

« Spotting » of microdroplets

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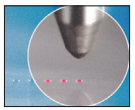

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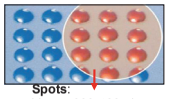

Spots:
$V_{droplet}$: 300-400 pL
$\varnothing_{droplet}$: 90-200 µm
until 600 spots / cm² !

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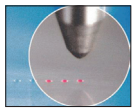

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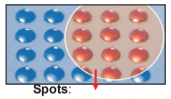

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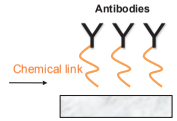

Ligands fixed on the support

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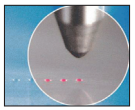

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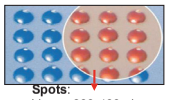

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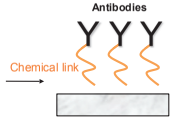

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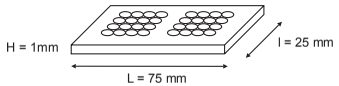

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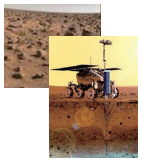
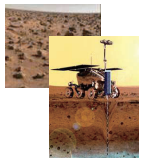


Sample extraction

Biochip

- Principle



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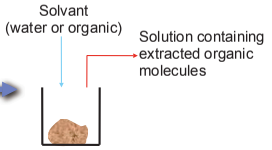

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Biochip

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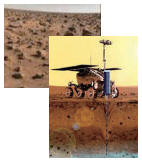

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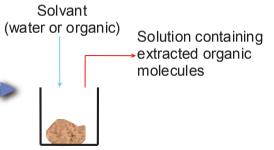

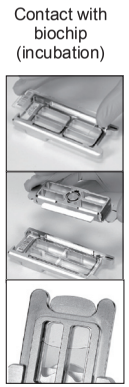

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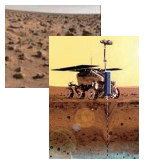

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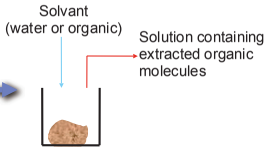

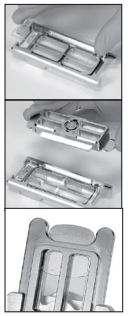

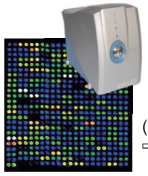

DETECTION in situ
by fluorescence of
ligands-biomarkers
(UV laser illumination)
⇨ linked ligands shine

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Biochip

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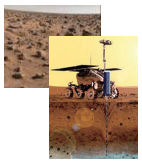

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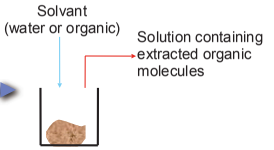
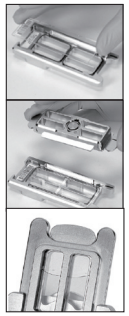
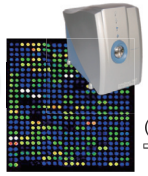




Target molecules ?



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Space mission constraints

Space mission constraints

- Vibrations and shocks
- Thermal variations
- Vacuum
- Microgravity
- Organic solvents for molecules extraction
- Cosmic radiations

⇨ Project BiOMAS-ARCoR : 2 steps presented here

① Simulation

② Experiment on beam facility

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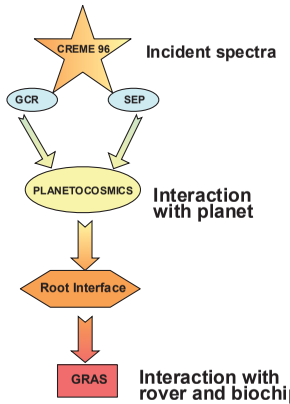
Simulation work to prepare experiments
→ *Definition of relevant types of particles and energy ranges*

Simulation strategy

At Mars surface



Incident spectra

Interaction with planet

Interaction with rover and biochip

- Use of 3 publicly available tools
- Development of 1 interface between Planetocosmics and GRAS.

Physics models used:
- ✓ *EM-Standard*
- ✓ *QGSP-BIC-HP*

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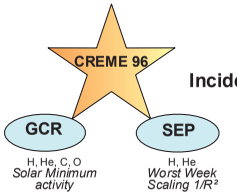

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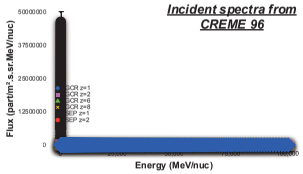
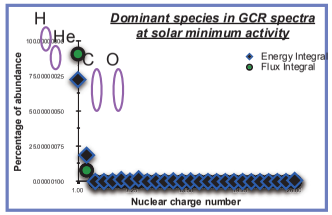


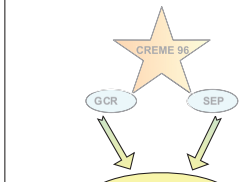


Representative species of the global spectrum:

- GCR: *Protons, Alphas, Carbon and Oxygen ions*
- SEP: *Protons, Alphas*

Simulation strategy

At Mars surface

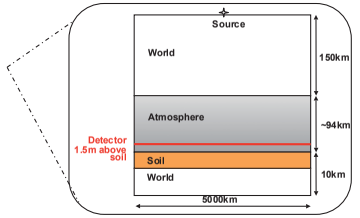


Spectra : H, He, γ, n, e-, e+, d, t, Li, Be, B, C, N, O
Normalization : TO-PRIMARY-FLUX option

Fluences of up and down particles above Mars surface

- **Geant4** based tool.
- Developed at the University of Bern.
- Simulation of particles interactions with **planets: soil** and **atmosphere**.

Planet scale



Atmosphere: MARS Gram 2001, 45°N, 180°E

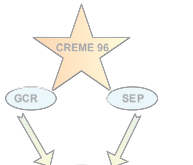
Soil:

Material	Na_2O	MgO	Al_2O_3	SiO_2	SO_3	K_2O	CaO	TiO_2	Fe_2O_3
Abundance [%]	1.5	7.7	8.1	46.8	6	0.2	6.2	1.1	18.8

From measurements on the Sojourner-Pathfinder mission

Simulation strategy

At Mars surface

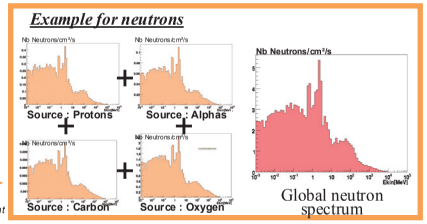


Global spectra : H, He, γ, n, e-, e+, d, t, Li, Be, B, C, N, O

Spectra sum + normalization

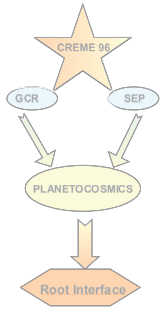
For each type of particle, make the sum of the different spectra detected from each type of incident particle

- Make the link between Planetocosmics results and GRAS inputs
- Special care to **normalization**: from the planet scale to the rover scale



Simulation strategy

At Mars surface

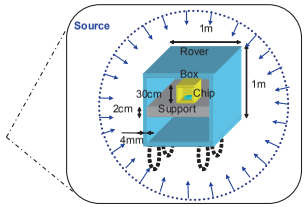


Ionizing dose, particles fluences

Results per event (per primary particle generated)

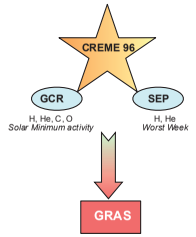
- **Geant4** based tool.
- Developed at the European Space Agency.
- GRAS: Geant4 Radiation Analysis in Space.
- Radiation simulation in the **space field**.

Rover scale



Simulation strategy

Earth-Mars travel



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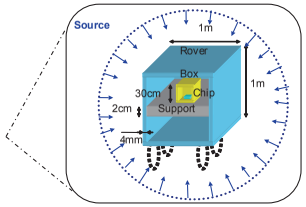


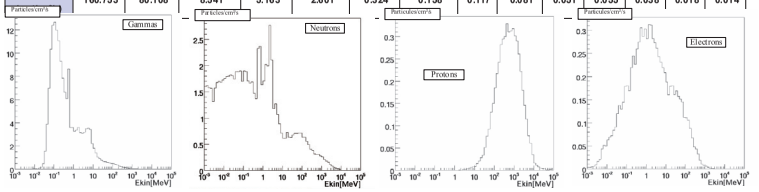
SIMPLIFIED STRUCTURE

Simulation results

At Mars surface

Particles fluxes at 1.5 m above soil (without SEP)

Particles	Gamma	Neutron	Electron	Proton	Positron	Alpha	Deuteron	O	Triton	Be	C	N	Li	B
Fluxes	160.753	80.108	8.541	5.163	2.601	0.324	0.158	0.117	0.081	0.051	0.055	0.038	0.018	0.014



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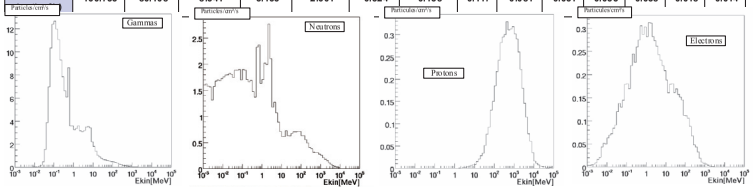

Ionizing doses in the biochip for a **ONE MONTH** stay on Mars soil

Particles	Proton	O	Gamma	N	Electron	C	Neutron
Doses (MeV)	1.98 10^8	1.95 10^8	5.28 10^7	4.84 10^7	4.80 10^7	4.72 10^7	4.02 10^7
Doses (Gy)	7.22	7.07	1.92	1.76	1.75	1.72	1.46
Particles	Positron	Alpha	Be	B	Deuteron	Li	Triton
Doses (MeV)	3.73 10^7	2.74 10^7	2.30 10^7	9.43 10^6	5.19 10^6	4.27 10^6	2.92 10^6
Doses (Gy)	1.36	1.00	0.84	0.34	0.19	0.16	0.11

Global dose = 7.39 10^8 MeV

26.9 mGy

1 Gy = 100 rad = 1J/kg
Biopsace : ~4.4 g
1 MeV = 1,6.10^{-13}J

Simulation results

Earth-Mars travel

Ionizing doses in the biochip for a **SIX MONTHS** Earth-Mars travel (without solar event)

Particles	Protons	Alphas	z=8 O	z=6 C	TOTAL
Dose (MeV)	8.79 10^8	3.32 10^8	1.24 10^8	5.68 10^7	1.39 10^9
Dose (mGy)	32	12.1	4.5	2.1	50.7

50.7 mGy

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Simulation results

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Ionizing doses accumulated in the biochip during a **SEVEN DAYS solar event** occurring along the 6 months travel

Particles	Protons	Alphas	TOTAL
Dose (Mev)	$5.12\ 10^{10}$	$5.37\ 10^8$	$5.17\ 10^{10}$
Dose (Gy)	1.86	$1.95\ 10^{-2}$	1.88

→ 1.88 Gy

Simulation results

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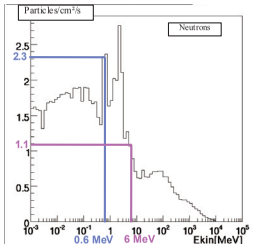
Solar particles events contribute largely to ionizing dose accumulation. Protons irradiation will be of crucial importance during the travel.

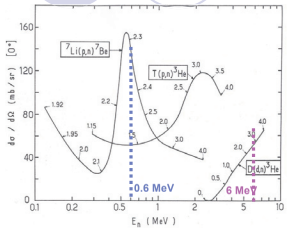
Irradiation experiment

- French beam facility (AIFIRA): 3 days beam time *(October 2007)*
- Neutron irradiation
- 2 energies: 0.6 and 6 MeV
- 2 types of molecules:
  - Antibodies
  - Fluorescent dyes
- 2 types of conditioning
  - In solution
  - Lyophilized
- Irradiation with 4 orders of magnitude in case Monte-Carlo predictions are under estimated:
  - Dose D for one month at Mars surface, 10D, 100D and 1000D

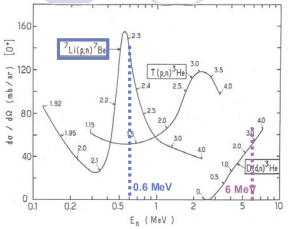


Global neutrons spectrum at soil level

Irradiation experiment



Irradiation experiment

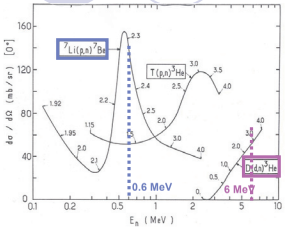


2 energies of neutrons

↳ 2 different methods:

- ✓ protons → Li 0.6 MeV
- ✓ deutons → D 6 MeV

Irradiation experiment



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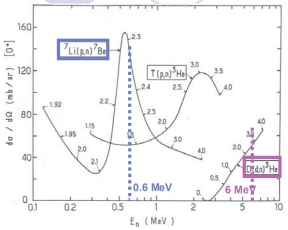

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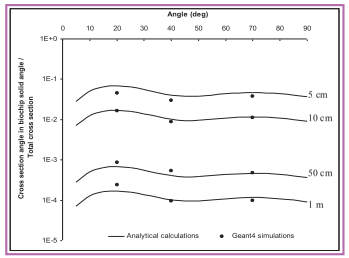
Positioning of samples: angle choice



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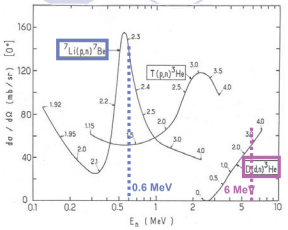
Irradiation experiment



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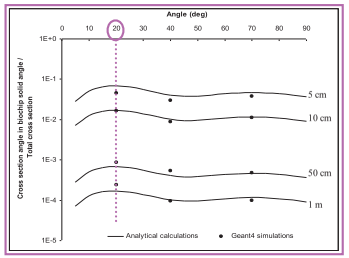

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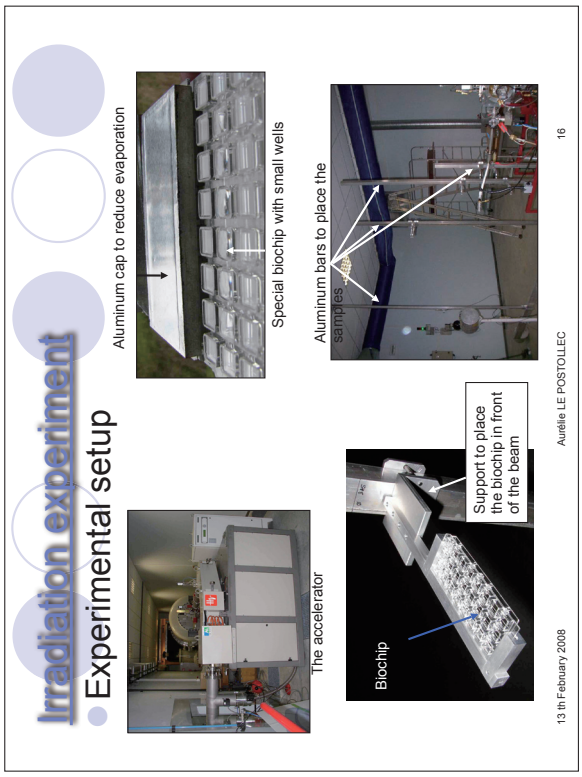
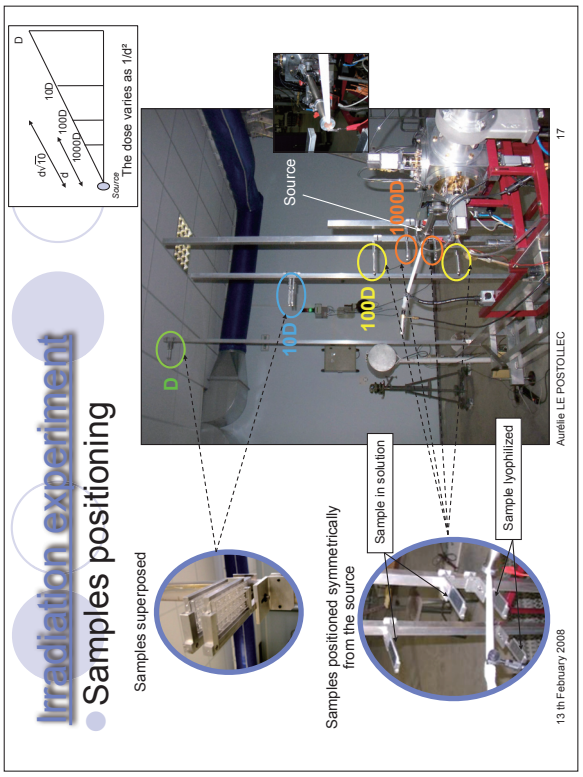
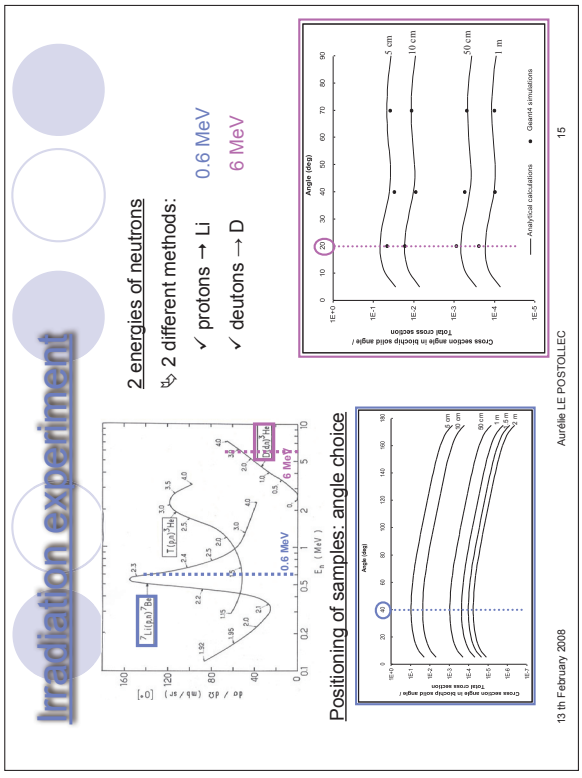
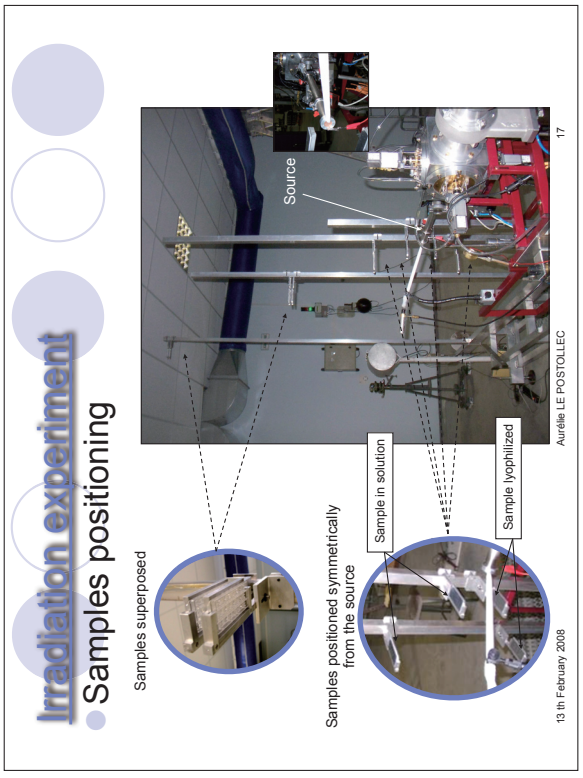








Irradiation experiment

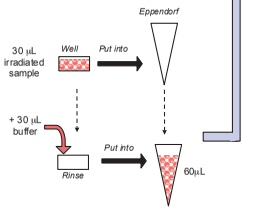
- 160 samples to analyze

(2 energies * 2 molecules * 2 conditioning * 4 replicates * 4 doses + 8*4 references)

Positions of molecules on the slide

	A	B	C	D	E	F	G	H
3								
2			Ab	Ab	Ab	Ab		
1			F	F	F	F		

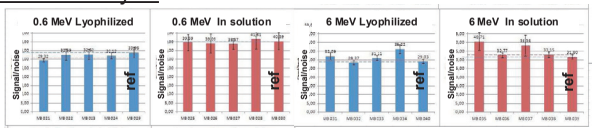
Samples recuperation after irradiation



Samples recuperation from the biochip and conditioning in hermetic tubes for transport

Experiment results

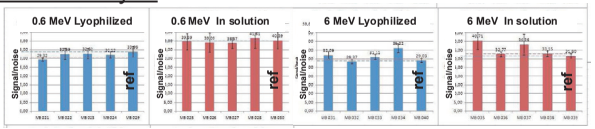
Fluorescent dyes



No influence of neutron radiation on fluoresceine performances.

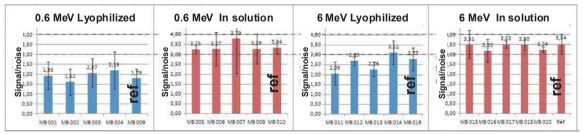
Experiment results

Fluorescent dyes



No influence of neutron radiation on fluoresceine performances.

Antibodies



No influence of neutron radiation on antibodies recognition capability.

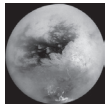
Process to lyophilize seems to lower antibodies performances.

⇨ Optimization under study

Perspectives

Longer term

- Simulations:
  - To improve rover design
  - To include high energy physics models (PHITS…)
  - To study new environments: ISS, Titan, etc…



- Experiments:
  - New experiments foreseen :
    - Other particles: gammas, protons…
    - Other samples: antibodies fixed on a slide, …
    - Other environments : inside a rover model, …

Next experience May 2008

Collaborators and Publications

- Collaborators

M. Dobrijevic	LAB	France
S. Incerti	CENBG	France
Ph. Moretto	CENBG	France
L. Desorgher	University of Bern	Switzerland
G. Santin	ESTEC-ESA	Netherlands
P. Nieminen	ESTEC-ESA	Netherlands
O. Vandenabeele-Trambouze	IBMM	France
G. Coussot	IBMM	France
I. Desvignes	IBMM	France
L. Dartnell	CoMPLEX	Great Britain

- Publications in preparation
  - *Monte-Carlo simulation of the radiation environment encountered by a biochip during a space mission to Mars* — SIMULATIONS
  - *Investigation of Neutron Radiation Effects on Antibodies and Fluorescent Dyes Dedicated to Astrobiology Applications* — EXPERIMENT

Thank you for your attention