

# Geant4 modelling and experiments at the National Cancer Center

Se Byeong Lee – National Cancer Center, Goyang-si, Korea

**on behalf of the Med-1/Protontherapy team**

TYL-FKPPL Joint Workshop, May 10-12, 2017

# Team



- Korea (National Cancer Center)

- Lee, Se Byeong
- Shin, Jae Ik
- Kim, Chan Kyu

- France

- Le Postollec, Aurélie (Laboratoire d'Astrophysique de Bordeaux)
- Dobrijévic, Michel (Laboratoire d'Astrophysique de Bordeaux)
- Sakata, Dousatsu (CENBG)
- Sarramia, David (LPC Clermont)
- Incerti, Sébastien (CENBG)



# Outline

- Overview of 2016 activities
  - Study of nanoparticles radiosensitization
  - Proton irradiation experiment for exobiology
  - Geant4 tutorial

# Proton beam facility at the National Cancer Center



## IBA Proteus 235

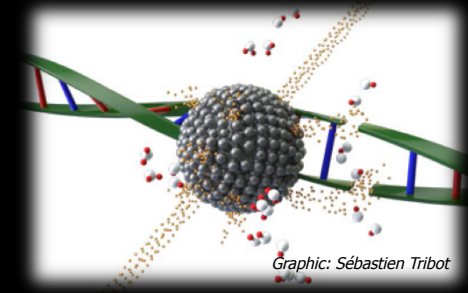
Weight : 220 tons Height : 210 cm Diameter : 434 cm

Energy : 230 MeV

Max. extracted beam current : 300 nA

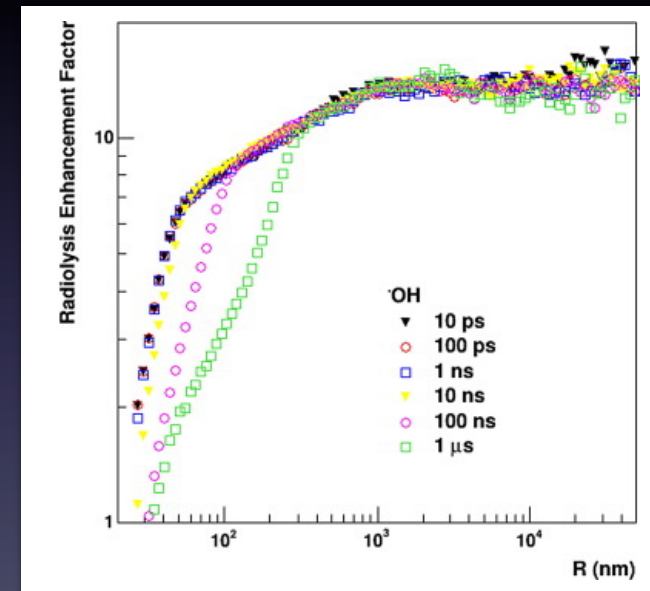
RF frequency : 106 MHz

# 1) Simulation of radiotherapy boost effects using high-Z nanoparticles



Graphic: Sébastien Tribot

- Hot topic: high-Z NP internalized in cells could boost energy deposition and thus increase the efficacy of radiotherapy treatments
  - Well established for photon beams (photoelectric effect), not so clear for proton beams in a context of protontherapy...
- Still a challenge to perform mechanistic simulations
  - We initiated a specific Geant4 activity on the subject in 2015
  - Requires the simulation of Auger cascades, simulation of chemical radical species production in the vicinity of NP
  - in collaboration with KEK group (T. Sasaki, K. Murakami, S. Okada) – see FJPPL project
  - in collaboration with Ton Duc Thang U. in Vietnam (H. Tran)



E.g. Radiolysis Enhancement Factor as a function of distance from GNP compared to WNP

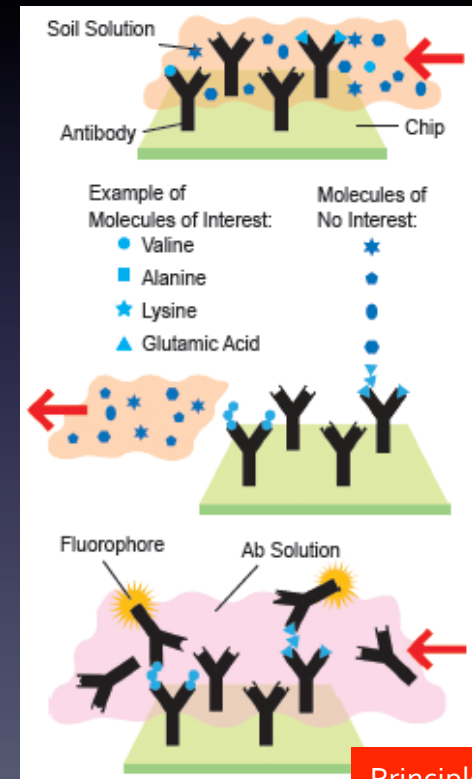
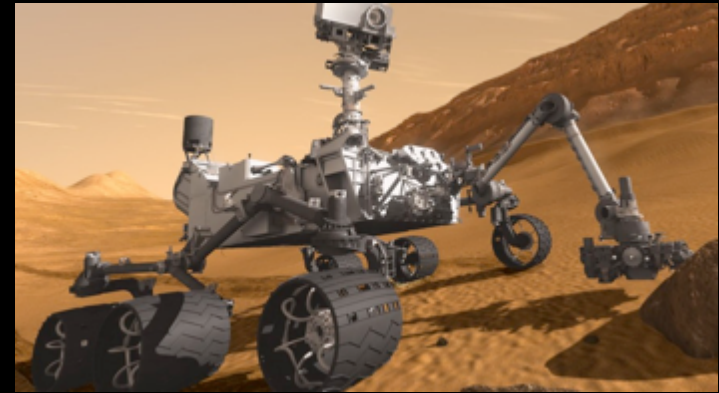
## 2) Protons for Astrobiology

Irradiation of hypothetical  
organic matter on Mars



# Context

- **Mars** exploration : the search for extraterrestrial life is one of the greatest challenges in the astrobiology field
- **Biochips** recommended by space agencies
- **SOLID project** (V. Parro et al. – Spain)
  - “Antibody” biochip to detect molecules of interest
  - free and grafted Ab
- Instrument proposed to **MARS2020 rover**



## Expected molecule targets

Table D.1-1. SOLID targets for Mars2020

Simple abiotic organics (Category 1)	LOD	Implications of detection
<b>Meteoritic amino acids</b> (Ala, Asp, Glu, Val, Ival, Ser)	<20	Elevated potential for biosignatures. Sample should be selected for return.
<b>PAHs</b> (Naphthalene, Pyrene, Anthracene, Quinoids)	<10	Meteorites deliver organics to Mars Building blocks of life are present
<b>Oxidation products</b> (Mellitic, Benzoic)	<5	
<b>Meteoritic nucleobases</b> (A, G, C, U, Xa)	TBD	
<b>Possible organic biomarkers (Category 2)</b>		
<b>Aromatic amino acids</b> (Phe, Tyr, Trp; α-AIB)	<20	High potential for biosignatures. Sample should be selected for return.
<b>Nucleotide &amp; derivatives</b> (AMP; GMP; C-GMP)	TBD	Prebiotic or biotic chemistry
<b>Hydrocarbons</b> (Alkanes, Kerogen, Alkyldibenzothiophene)	<500	
<b>Definitive organic biomarkers (Category 3)</b>		
<b>Hydrocarbons</b> (Isoprenoid, Carotenoid, Alkylphenanthrene)	<500	Definitive biosignatures Life once existed on Mars
<b>Lipids</b> (Hopanes, Steranes, Lycopanes, Carotanes)	<500	Sample should be selected for return.
<b>Polymers</b> (Peptides, Nucleic Acids, Polysaccharides)	<5	Planetary Protection concerns
<b>Heterocycles</b> (Porphyrin ring)	<5	
<b>Forward Contamination (Category 4)</b>		
<b>Earth Organisms</b> ( <i>Bacillus</i> , <i>Streptomyces</i> , <i>Pseudomonas</i> , <i>E. coli</i> , <i>Clostridium Propionibacterium</i> )	*10 <sup>-3</sup> to *10 <sup>-4</sup>	There has been forward contamination with Earth microorganisms

LOD - Lower Limit of Detection ppb (ng/ml) in sample extract. \*Cells/gram (x - y ppb organics). TBD - To be developed - possible descope option.

**SOLID**  
Signs of Life Detector

Searching for Evidence of Past Life on Mars

Submitted by Principal Investigator: Dr. Victor Parro Garcia  
Centro de Astrobiología (INTA – CSIC) Spain

Proposed to NASA  
Announcement of Opportunity  
NNH13ZDA0180 on 15 Jan 2014

Authorizing Official: Dr. Javier Gómez-Elvira  
Director, Centro de Astrobiología (INTA – CSIC) Spain

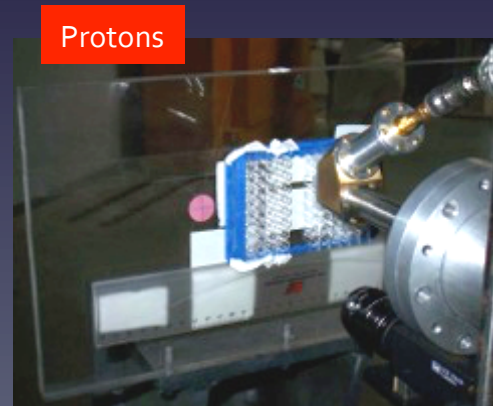
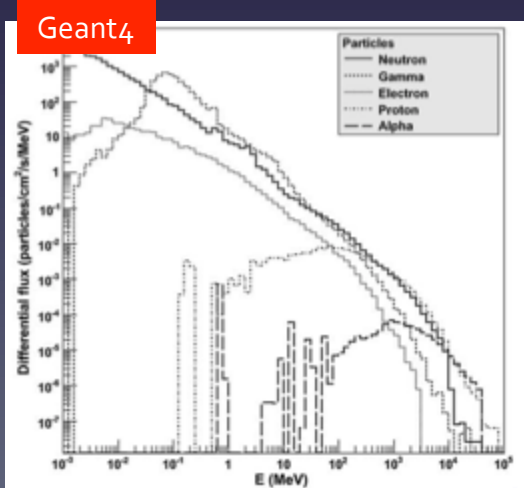
Supported by NASA Ames Research Center  
Co-PI Dr. Carol Stoker

CENTRO DE ASTROBIOLOGÍA  
ASOCIACIÓN PARA ASTROBIOLOGÍA ESPAÑA

## Principle

# History

- Long term collaboration between Laboratoire d'Astrophysique de Bordeaux and CENBG
  - 10 publications, 1 PhD
- Geant4 simulations
  - Radiation environment of a biochip on a mission to Mars
  - Radiation environment outside the International Space Station
  - Preparation of irradiation experiments with several beam types
- Irradiations on AIFIRA platform@CENBG to study antibody resistance to protons and neutrons





# More antibody irradiations

- Protons and neutrons irradiations at Louvain-la-Neuve (Belgium)
- C and O ions irradiations at LNS Catania (Italy)
- Electrons at Bergonié Institute in Bordeaux

➡ Showed resistance to radiation

- EXPOSE-R2 mission outside the International Space station for 18 months (ISS) (analysis in progress)

Protons, neutrons @ Louvain



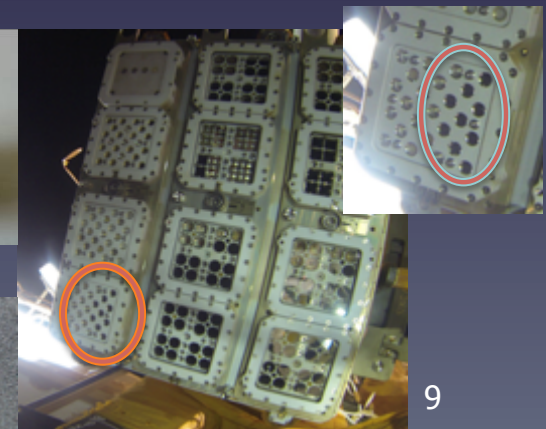
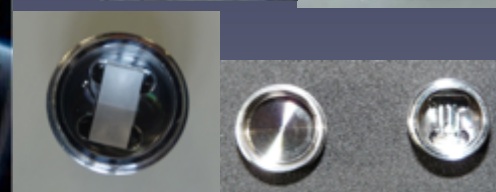
C, O @ LNS



Electrons @ Bergonié



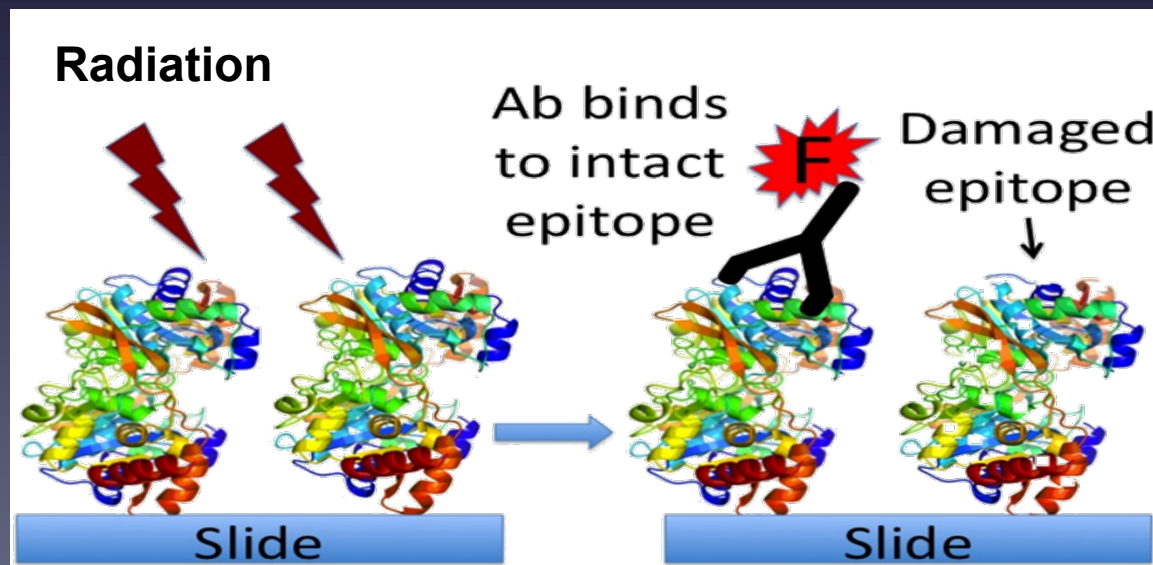
ISS



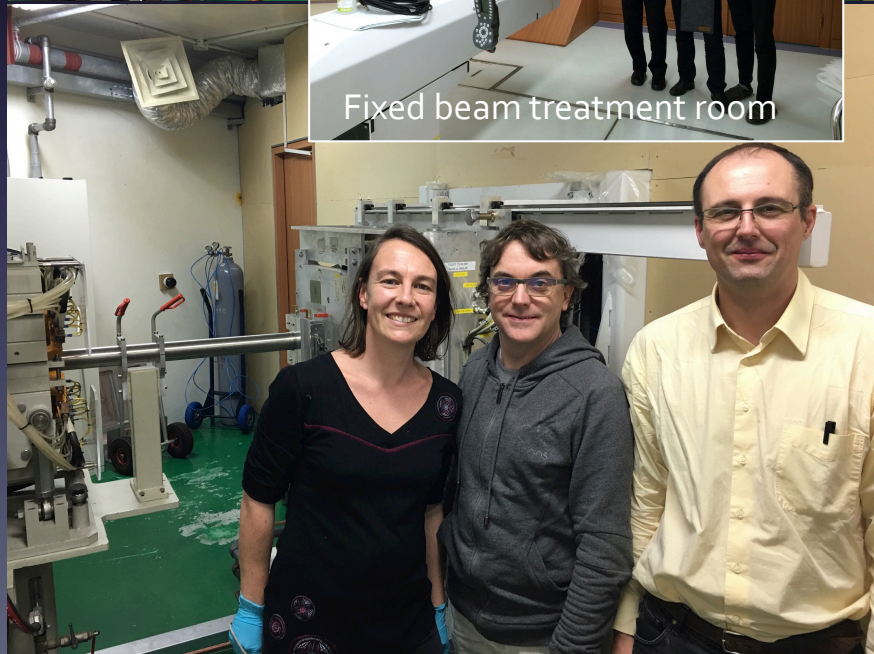
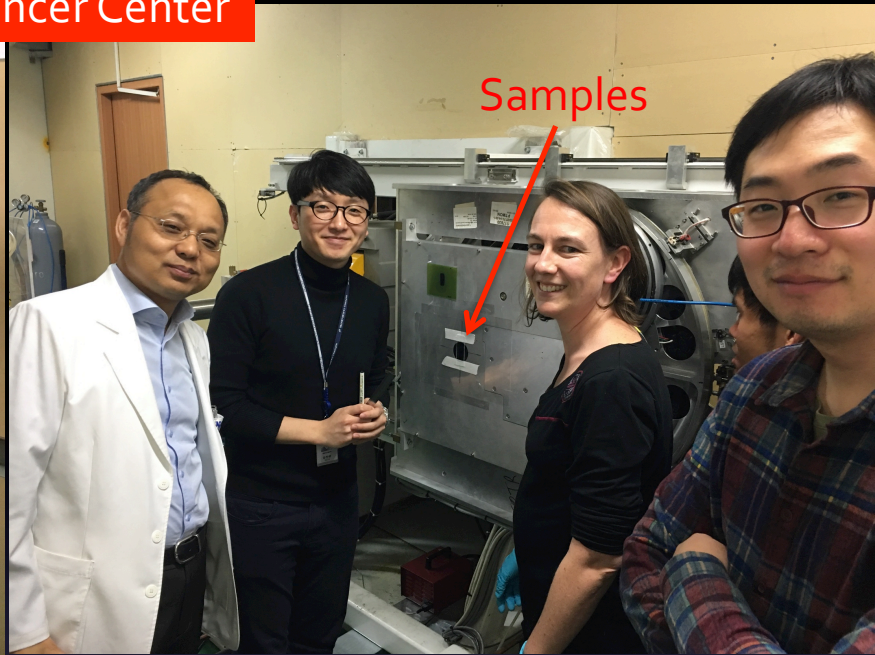
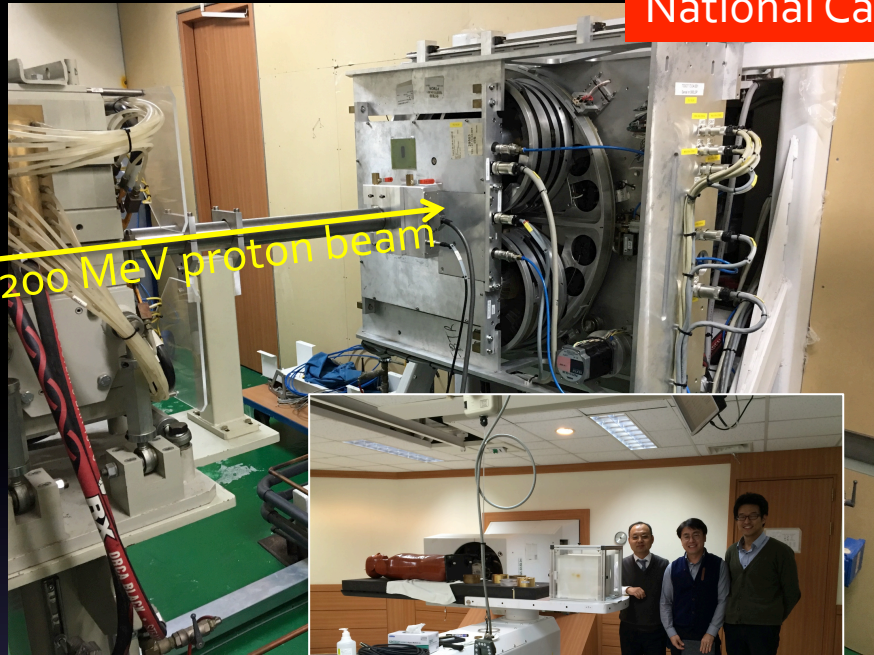
# Next step

To reproduce **long time irradiation** (high dose radiation) of **molecules** (**epitope**) in order to confirm that a biochip (constituted of antibodies) could detect them even if they have been degraded by a long journey at Mars surface.

- **Target molecules (epitopes)** are irradiated (not ligands !)
- Molecules exposed to doses reproducing a very long time irradiation at Mars surface (**around 1-10 My**) – 0.2 mGy/day on Mars – 1 My = 77 kGy



National Cancer Center



- Analysis is on-going

# Irradiation @ AIFIRA - CENBG

- March 8, 2017
- Energy: 3 MeV
- Current : 550 pA
- Flux:  $9E9$  p/cm<sup>2</sup>/s
- 2 doses : 50 kGy and 500 kGy
- 12 slides
  - 10 slides to irradiate: 5 slides/dose
  - 2 reference slides
- Analysis is on-going...



# 3) Outreach : Geant4 tutorial

<https://hep.kisti.re.kr/indico/conferenceDisplay.py?ovw=True&confId=214>



- Strong support of **FKPPL** and Korean institutions (**KISTI, NCC**) for the organization of **regular Geant4 tutorials in Korea**
- For **HEP and medical physics** communities
- This year, **40** participants (PhD students, postdocs, researchers)
- **3** teachers: **M. Asai (SLAC), M. Novak (CERN), S. Incerti (IN2P3)**
- **7** tutorials since **2009** in Rep. Korea
  - **Geant4 tutorial, Dec. 9-10, 2016 – KISTI, Daejeon, Rep. Korea**
  - Geant4 tutorial, Oct. 30 - Nov. 1, **2015** - National Cancer Center, Ilsan, Rep. Korea
  - Geant4 tutorial, October 27-29, **2014** - KISTI, Seoul, Rep. Korea
  - Geant4 Tutorial - October 29 - November 2, **2012** - KISTI, Seoul, Rep. Korea
  - 2011 Fall Training Course on Geant4 and GATE - October 31- November 4, **2011** - KISTI, Seoul, Rep. Korea
  - 2010 Summer Training Course on Geant4, GATE and Grid Computing - July 7-10, **2010** - Seoul, Rep. Korea
  - Introduction to Geant4, November 10, **2009** - KISTI, Daejeon, Rep. Korea

# Future

- Continuation of **NCC irradiation experiments for astrobiology**
  - Smaller dose rates ?
  - Publication to prepare
- A **5-day Geant4 general scope tutorial** in Seoul in July 2016
- Deliver in Geant4 an example demonstrating the **combination of Geant4-DNA physics+chemistry+Gold NP** in a realistic cellular nucleus (after publication)

# Publications

- 2 publications
  - **Geant4 Monte Carlo simulation of absorbed dose and radiolysis yields enhancement from a gold nanoparticle under MeV proton irradiation**, H. N. Tran, M. Karamitros, V. Ivantchenko, S. Guatelli, S. McKinnon, K. Murakami, T. Sasaki, S. Okada, M.C. Bordage, Z. Francis, Z. EL Bitar, M. A. Bernal, J. I. Shin, S. B. Lee, Ph. Barberet, T.T. Tran, J. M. C. Brown, S. Incerti, [Nucl. Instrum. Meth. B 373 \(2016\) 126-139](#)
  - **Recent developments in Geant4**, J. Allison et al., by the Geant4 Collaboration, [Nucl. Instrum. Meth. A 835 \(2016\) 186-225](#)



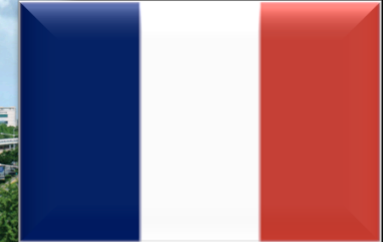
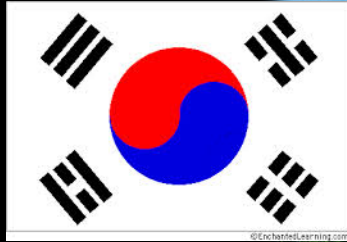
# Meeting with **NRF** on Dec 7th

- **FKPPL management** : P. Ko, S. Hwang, D. Sarramia, S. Incerti
- **French embassy** Science Attaché & chargée de mission : E. Franco-Ritz, E. Cuinet
- **NRF directorate**: Jong Deok Kim, director of international programs for Europe & Africa, Mrs Kim in charge of France-Korea programs



Triggered France-Korea CNRS-NRF Call 2018-2019





Thanks for your attention !