Monte-Carlo Simulation of Heavy Ion Track Structure
Calculation of local dose and 3D time evolution of radiolytic species

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### Importance of heavy ions
- Heavy ions have gained considerable importance in radiotherapy due to their advantageous dose distribution profile and high Relative Biological Effectiveness (RBE)
- Heavy ions are difficult to produce on Earth, but they are present in space and it is impossible at this moment to completely shield astronauts from them
- The risk of these radiations is poorly understood, which is a concern for a 3-years Mars mission [1]

### Interaction of radiation with biological media
- The effects of radiation are mainly due DNA damage such as DNA double-strand breaks (DSBs), although non-targeted effects are also very important
- DNA can be damaged by the direct interaction of radiation and by reactions with chemical species produced by the radiolysis of water [2]
- The energy deposition is of crucial importance to understand biological effects of radiation
- Therefore, much effort have been done recently to improve models of radiation tracks

### Energy deposition by ionizing radiation
- Primary energy loss events in low-LET tracks [3]
- Primary energy loss events in high-LET tracks [4]

### Simulation of heavy ion tracks
- The radiolysis of water is simulated by Monte-Carlo methods, a mathematical technique used to simulate stochastic systems
- A cube of 5\(\mu\)m x 5\(\mu\)m x 5\(\mu\)m is irradiated by a \(^{56}\text{Fe}^{26+}\), 1 GeV/amu ion (LET~150 keV/\(\mu\)m) and by 450 \(^1\text{H}^+\), 300 MeV/amu ions (LET~0.3 keV/\(\mu\)m) for a total dose of \(\sim\)100 Gy
- The dose is calculated in voxels of 20 nm x 20 nm x 20 nm
- The spatial distribution of dose is different for high and low-LET radiations
- In both high and low LET radiations, many voxels receive a low dose. Voxels which receive very high dose appears only in high-LET tracks.

### Discussion
- The 3D distribution of dose voxels calculated by RITRACKS have an appearance very similar to DSB observed with \(\gamma\)-H2AX experiments
- In addition, since high-dose voxels appear only in high-LET radiation and DSBs which are difficult to repair are found only in high-LET tracks, we may hypothesis that DSBs created within these high-dose voxels may be of different nature than those created by low-LET radiation.

### Conclusion
- Heavy ions are used in radiotherapy because of their dose distribution profiles and high RBE; however, they may also pose a substantial but poorly understood risk for astronauts on a 3 years Mars mission

### References
[7] Mathew, B. et al. (2008), DNA repair 7, 1717-1730

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**Monte-Carlo track structure simulations can be used to calculate dose deposited in an irradiated volume by high and low-LET radiation**

**These simulations can contribute significantly to the understanding of DNA damage and non-target effects of ionizing radiation by providing important information such as the dose distribution as well as the 3D time evolution of the radiolytic species**

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**Distribution of DNA damage within cell nuclei**

- Experimental distribution of DSBs in fibroblast nuclei observed in \(\gamma\)-H2AX experiments for \(\gamma\)-rays and \(^{56}\text{Fe}^{26+}\), 1 GeV/amu ions (left). DSBs remaining as a function of time for these ions (right) [7]