# WRMISS - 2024

Denver, CO, USA
September 5, 2024

# Variations in the Radiation Environment and Observed Biological Consequences on the Long-Term Stored Embryonic Stem Cells in the Kibo Module of the ISS

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Radiation Institute for Science and Engineering (RaISE)
A Texas A&M Chancellor's Research Initiative (CRI)
*Prairie View A&M University*
www.pvamu.edu/raise

*This talk is dedicated to the memory of*
***Prof. Richard Wilkins (1960-2024)***
*Prairie View A&M University*

# Authors and Principals

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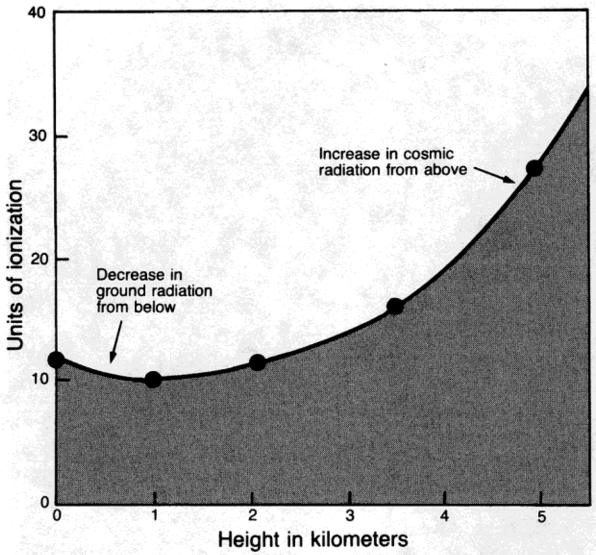
# BACKGROUND

Historical and Current

# 100+ Years of History: 1912-2012
# Discovery of Cosmic Rays - **Victor Hess**

Victor Francis Hess
B 1883 Peggau, Austria
D 1964 New York, USA

- Victor Hess - 1912
  - Investigated sources of radiation – a balloon trip to 5300 m (risking life)
  - Radiation levels to be higher after 2500 m
  - Attributed to the fact that there was less atmosphere above to shield from radiation – source outside
- Concluded - radiation is coming from space ... **“cosmic radiation”**
- Won Nobel Prize - 1936



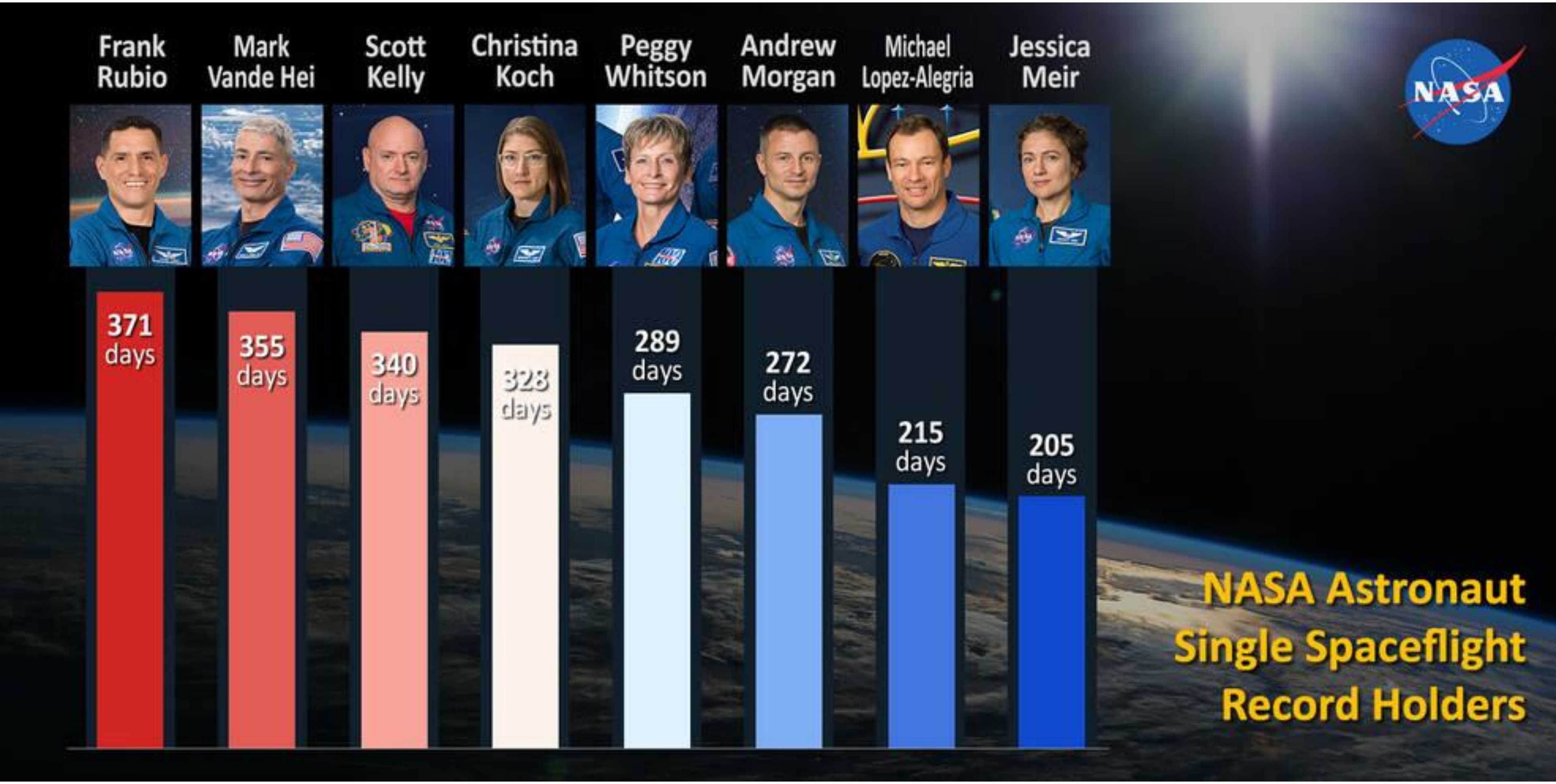

Readings on ionization chamber Victor Hess carried aloft in the Böhmen. Above four kilometers the ionization rose rapidly indicating "that rays of very great penetrating power are entering our atmosphere from above". These cosmic rays contain the only modern samples of matter from outside our solar system which can be investigated directly.

**September 27, 2023**: Astronaut **Frank Rubio** lands on Earth after **371 days on ISS** – longest US record with 5,963 orbits around the Earth, travelling 157.4 million miles (or 253.3 million km).

*Nasa astronaut Frank Rubio has just returned from a record-breaking 371 days in space onboard the ISS, but the trip* ***may have <u>altered his muscles, brain and even the bacteria</u>*** *living in his gut*



*https://www.bbc.com/future/article/20230927-*


Frank Rubio
Mark Vande Hei
Scott Kelly
Christina Koch
Peggy Whitson
Andrew Morgan
Michael Lopez-Alegria
Jessica Meir
NASA
371 days
355 days
340 days
328 days
289 days
272 days
215 days
205 days
NASA Astronaut Single Spaceflight Record Holders

*nasa.gov*

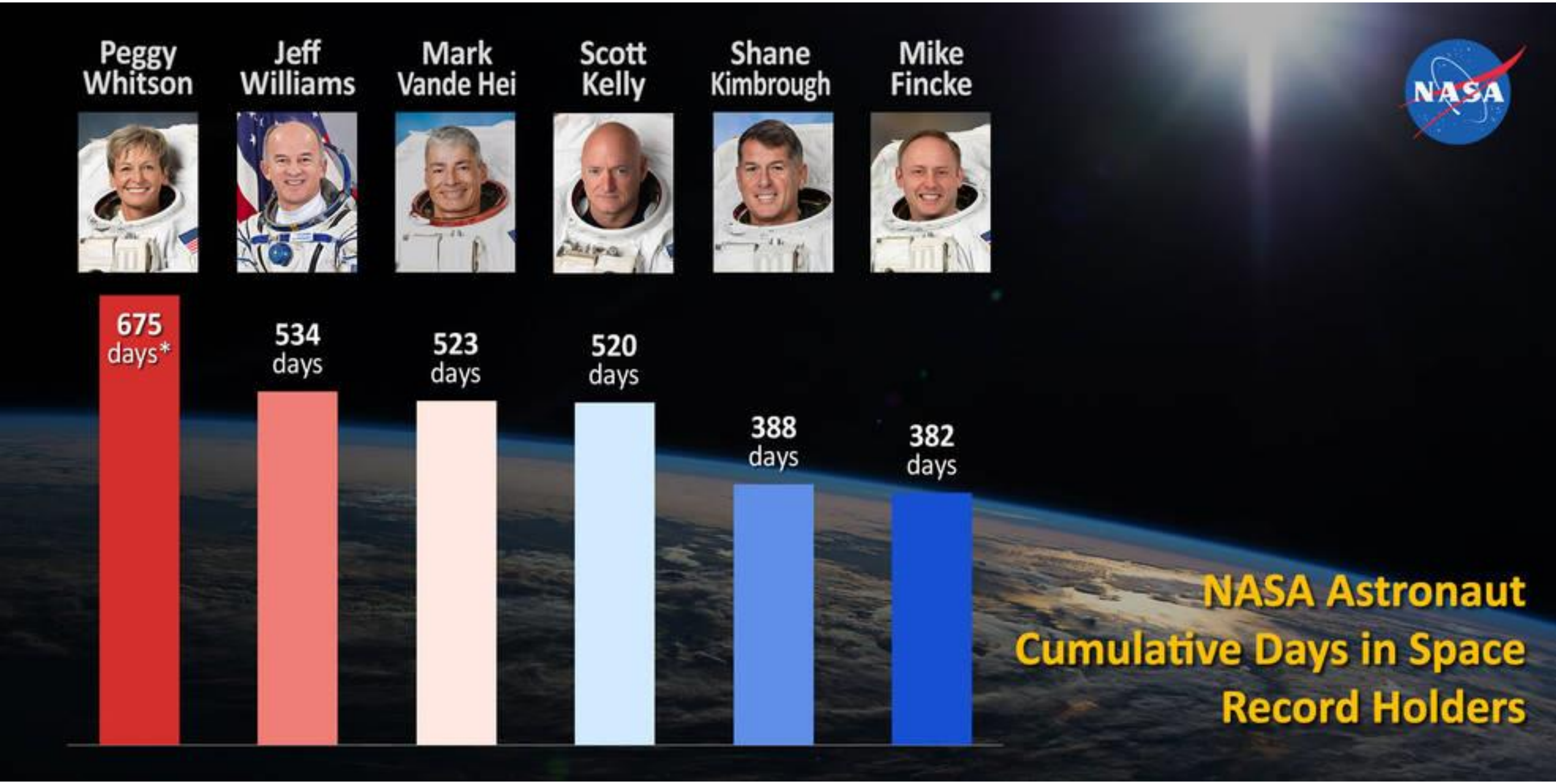

Credit: Frank Cucinotta, Johnson Space Center, and Prem Saganti, Lockheed Martin

**Dr. Peggy Whitson**

More time in space by any American / woman **~ 666** days (over 3 expeditions)
10 EVAs (~ **60** hrs outside ISS)

Private – Axiom-02 (2023) + **9** days

*"She is still the oldest woman to orbit the Earth, a record she broke in 2023, at 63"*


Peggy Whitson
Jeff Williams
Mark Vande Hei
Scott Kelly
Shane Kimbrough
Mike Fincke
NASA
675 days*
534 days
523 days
520 days
388 days
382 days
NASA Astronaut
Cumulative Days in Space
Record Holders

*nasa.gov*

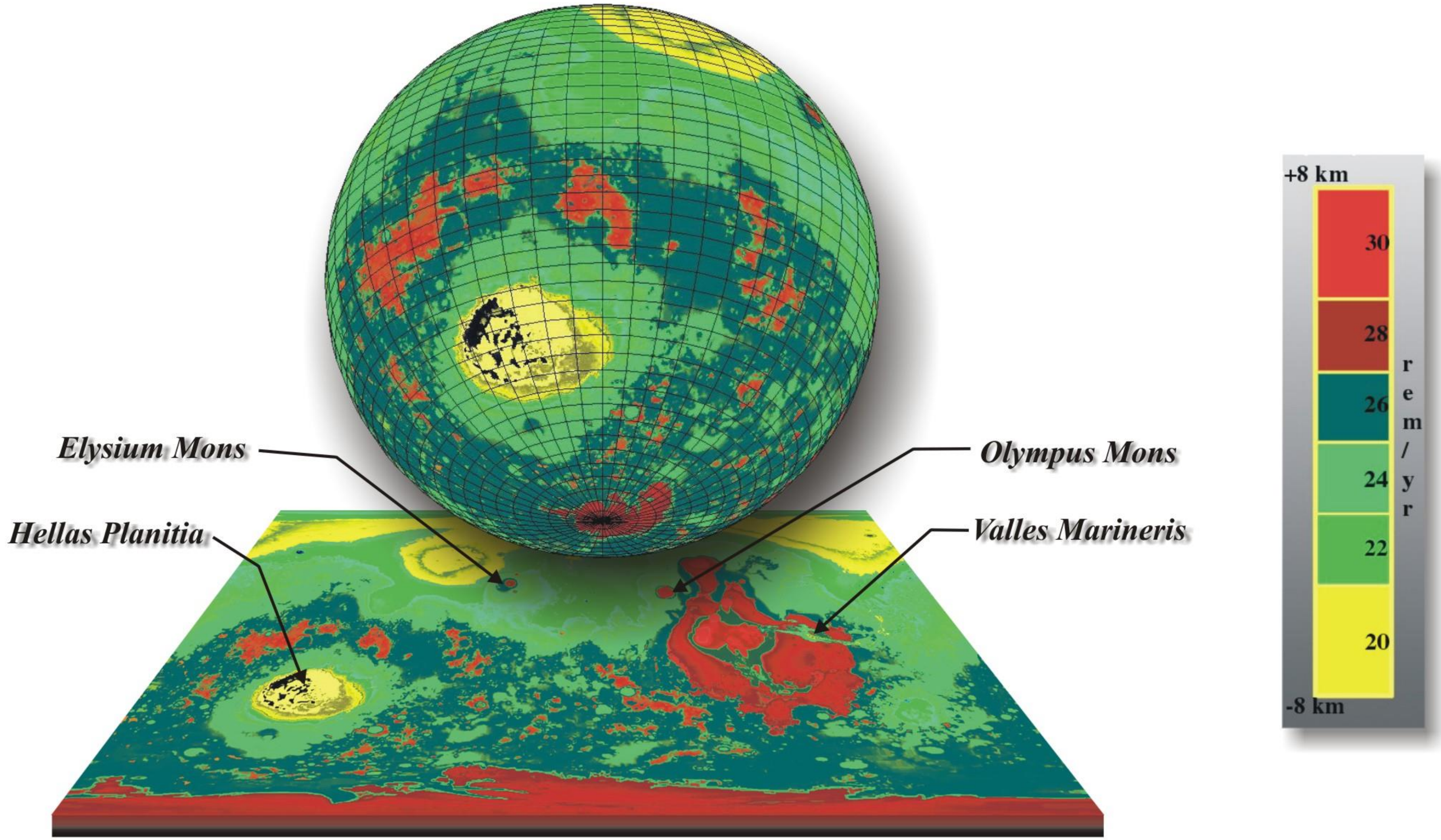
# September 4, 2024

| Rank | Name | Days | Flights | Status | Nationality |
|---|---|---|---|---|---|
| 1 | Oleg Kononenko | 1092 | 5 | (on ISS now) | Russia |
| 2 | Gennady Padalka | 878 | 5 | Retired | Russia |
| 3 | Yuri Malenchenko | 827 | 6 | Retired | Russia |
| 4 | Sergei Krikalev | 803 | 6 | Retired | Soviet Union / Russia |
| 5 | Aleksandr Kaleri | 769 | 5 | Retired | Russia |
| 6 | Sergei Avdeyev | 748 | 3 | Retired | Soviet Union / Russia |
| 7 | Anton Shkaplerov | 709 | 4 | Retired | Russia |
| 8 | Valeri Polyakov | 679 | 2 | Deceased | Soviet Union / Russia |
| 9 | Peggy Whitson | 675 | 4 | Active | United States |
| 10 | Fyodor Yurchikhin | 673 | 5 | Retired | Russia |

As of today (Sept 4, 2024)
**50** people spend more than **365** days in space

Source: *Wikipedia*

# Radiation Climate on Mars






Saganti / Cucinotta : *Space Science Reviews*, 110, 143-156, 2004

# Mars Exploration – NASA

Jet Propulsion Laboratory
California Institute of Technology

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JPL HOME | EARTH | SOLAR SYSTEM | STARS & GALAXIES | TECHNOLOGY

## Mars Exploration Program Analysis Group (MEPAG)

*chartered by NASA HQ to assist in planning the scientific exploration of Mars*

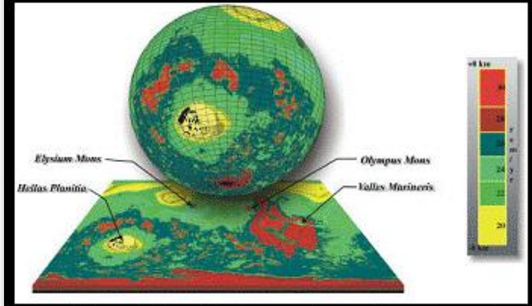
Home | Reports | Meetings | Announcements | Other

TOP 10

4. Radiation

2005: IVA-5
2010: 2B
Priority: Medium

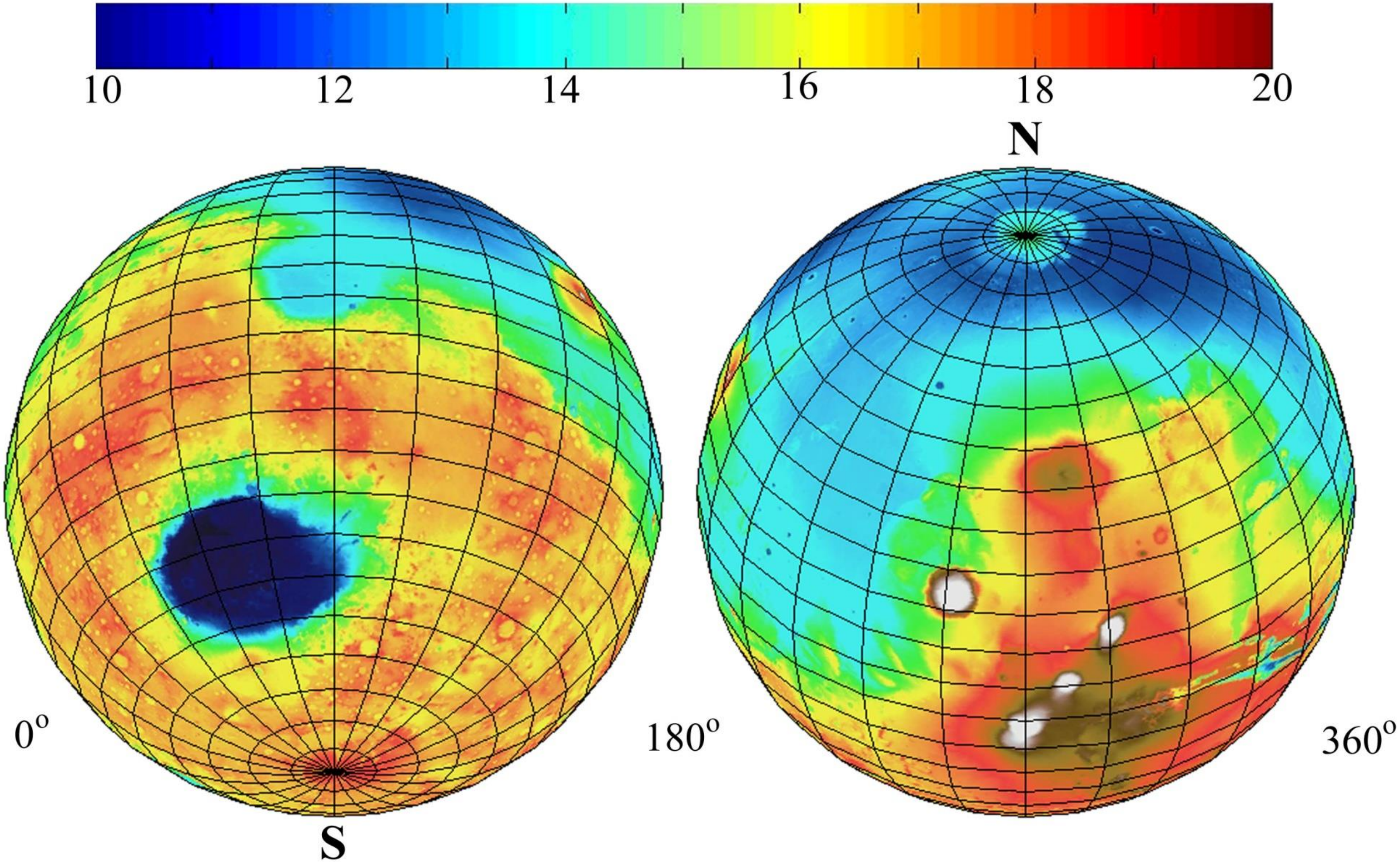
**Investigation**: Characterize in detail the ionizing radiation environment at the Martian surface, distinguishing contributions from the energetic charged particles that penetrate the atmosphere, secondary neutrons produced in the atmosphere, and secondary charged particles and neutrons produced in the regolith.




Calculations of the skin dose equivalent for astronauts on the surface of Mars near solar minimum. The variation in the dose with respect to altitude is shown. *Image Credit: Saganti, et al 2004*

# Mars Cosmic Ray Environment

Dose Equivalent Values (rem/yr)




Cucinotta / Saganti JRR 2003

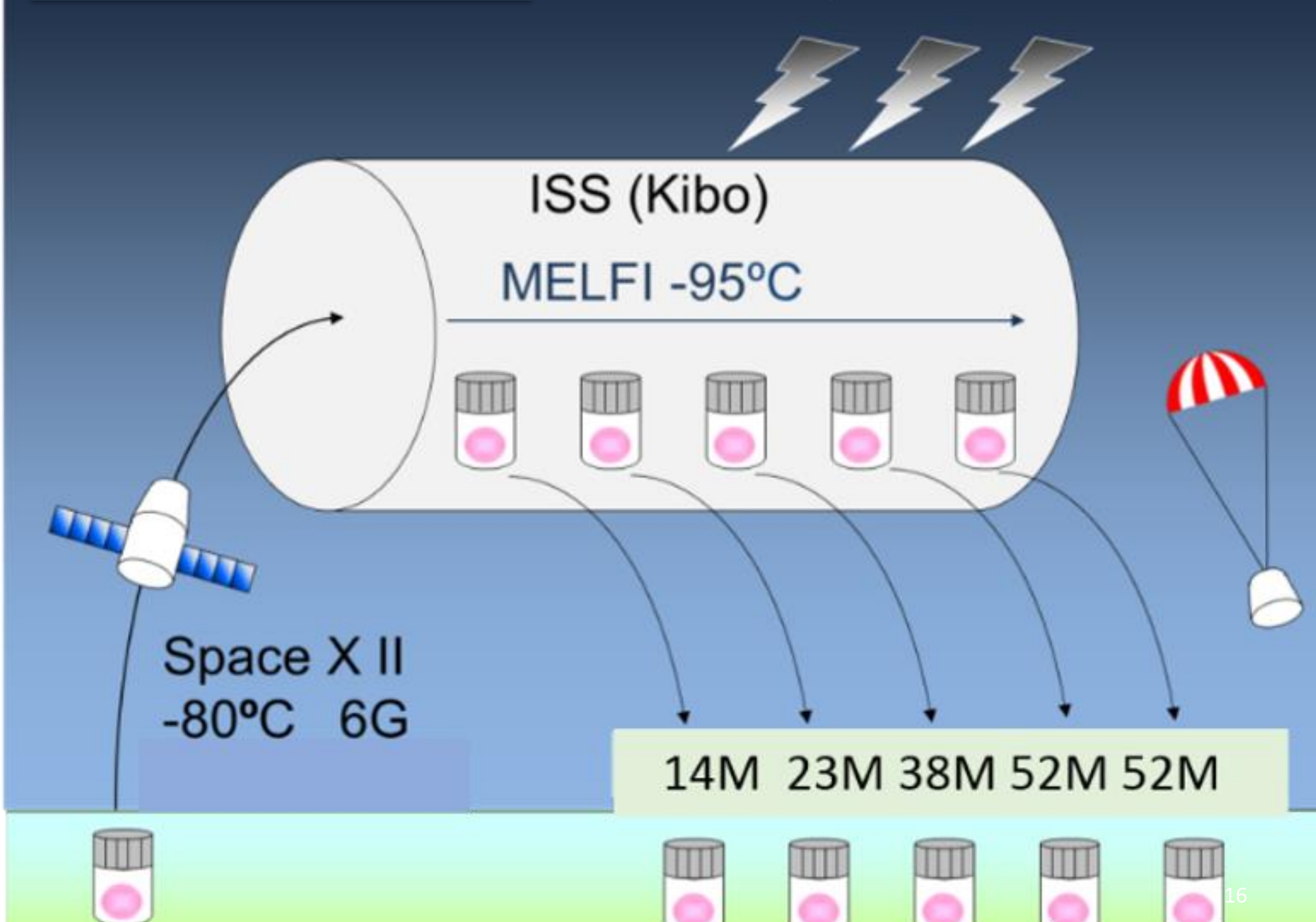
# Mars Radiation
# Predictions and Observations

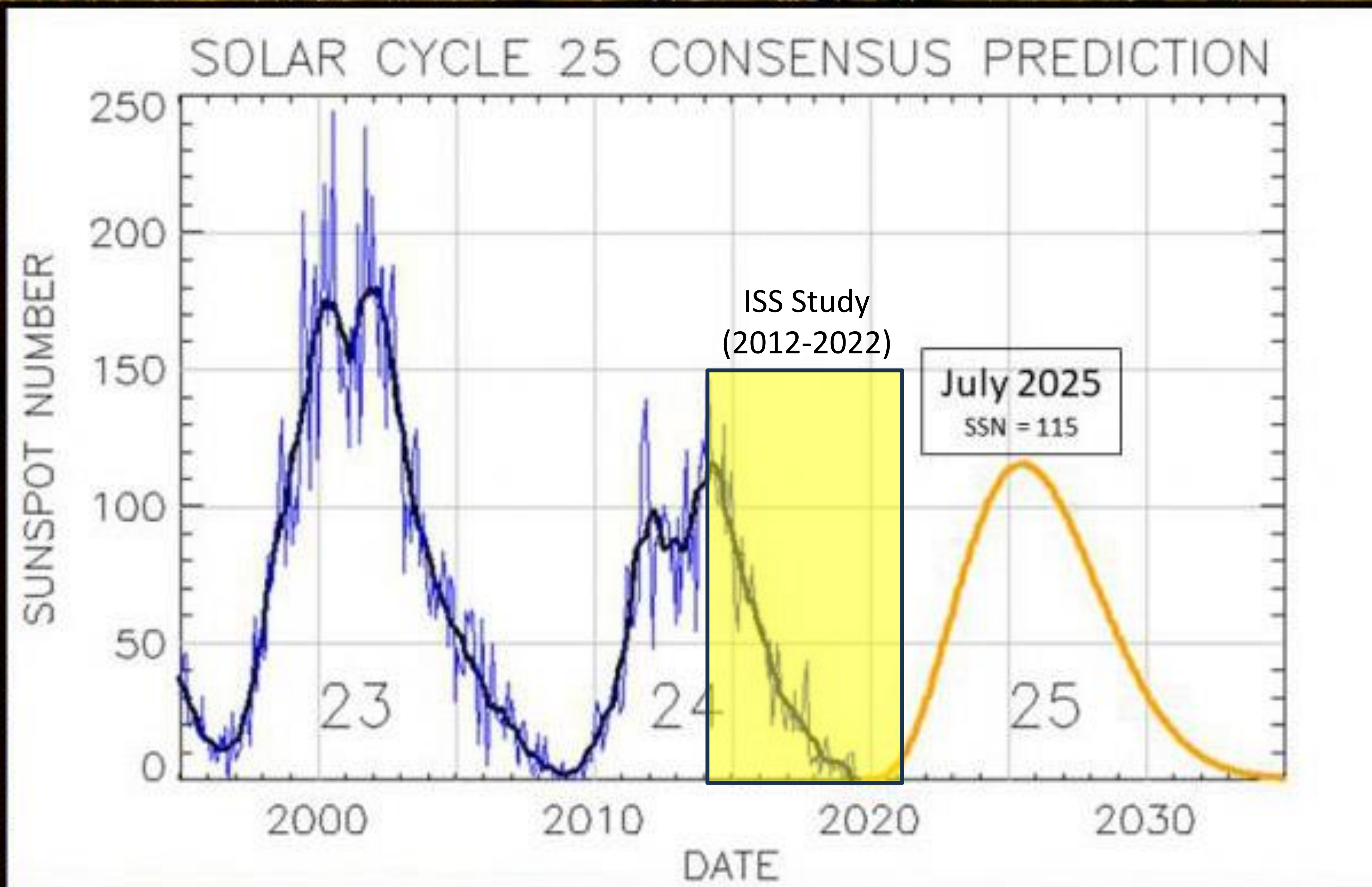
| Comparison | GCR Dose Rate (mGy/day) | GCR Dose Equiv. Rate (mSv/day) |
|---|---|---|
| | | |
| RAD Mars Surface Measurements (Hassler / Zeitlin 2014) | 0.205 ±0.05 | 0.70 ±0.17 |
| Model Calculations … Saganti / Cucinotta 2002 (Based on Solar Cycle # 23) | 0.212 | 0.65 |
| Model Calculations … Saganti / Cucinotta 2015 (updated for Solar Cycle # 24) | 0.232 | 0.74 |

# Overview

- A joint collaborative space project between JAXA and NASA
  - “Stem Cells - Study on the Effect of Space Environment to Embryonic Stem Cells to their Development” in the Kibo Module.
- Frozen Embryonic Stem (ES) cells were launched to ISS in
  - Stored in the Minus Eighty Degree Laboratory Freezer for ISS (MELFI) March 2013 through July 2017.
- Four different sets of cell samples were retrieved back to earth
  - After periods of 443 days, 711 days, 1167 days, and 1584 days on the ISS
  - Along with the PADLES (Passive Dosimeter for Life-science Experiments in Space)
  - PADLES consisting of CR-39 and TLDs) dosimeters attached to the tubes (ES cells).
- After these ES cell stacks were brought back to the ground, they were thawed and cultured, and their gene expressions were comprehensively analyzed to elucidate the early response of the cells to long-time exposure to space radiation in microgravity conditions.

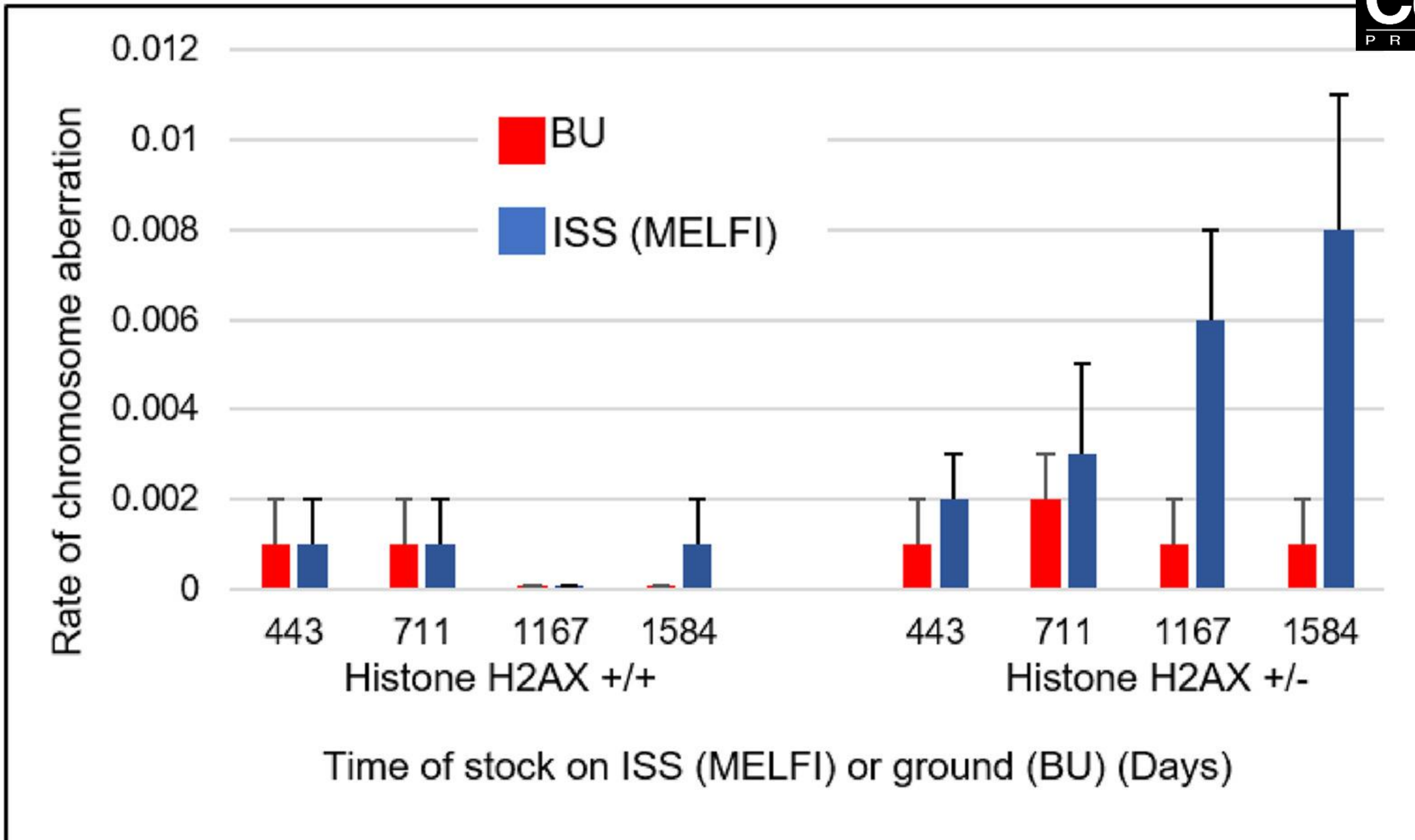
# “Stem Cells” @ ISS




SOLAR CYCLE 25 CONSENSUS PREDICTION
SUNSPOT NUMBER
250
200
150
100
50
0
2000
2010
2020
2030
DATE
23
24
25
ISS Study
(2012-2022)
July 2025
SSN = 115

# Observations

- The comparisons of gene expression involved in double-stranded break (DSB):
  - Also, the expressions of most of the genes that were involved in homologous recombination (HR) and non-homologous end joining (NHEJ) were studied and compared between the ISS-stocked cells and ground-stocked control cells.
- It was noted that the transcription of Trp53inp1 (tumor protein 53 induced nuclear protein-1), Cdkn1a (p21), and Mdm2 genes increased in ISS-stocked cells.
  - This phenomenon is similar to the cells that were exposed to the Fe ions in ground-based experiments at HIMAC Facility.
  - This suggests that accumulated DNA damage caused by space radiation exposure would activate these genes.
- The PADLES measured dose-equivalent values on ISS:
  - 250 mSv (for 443 days),
  - 375 mSv (for 711 days),
  - 575 mSv (for 1167 days), and
  - 830 mSv (for 1584 days) between 2013 and 2017

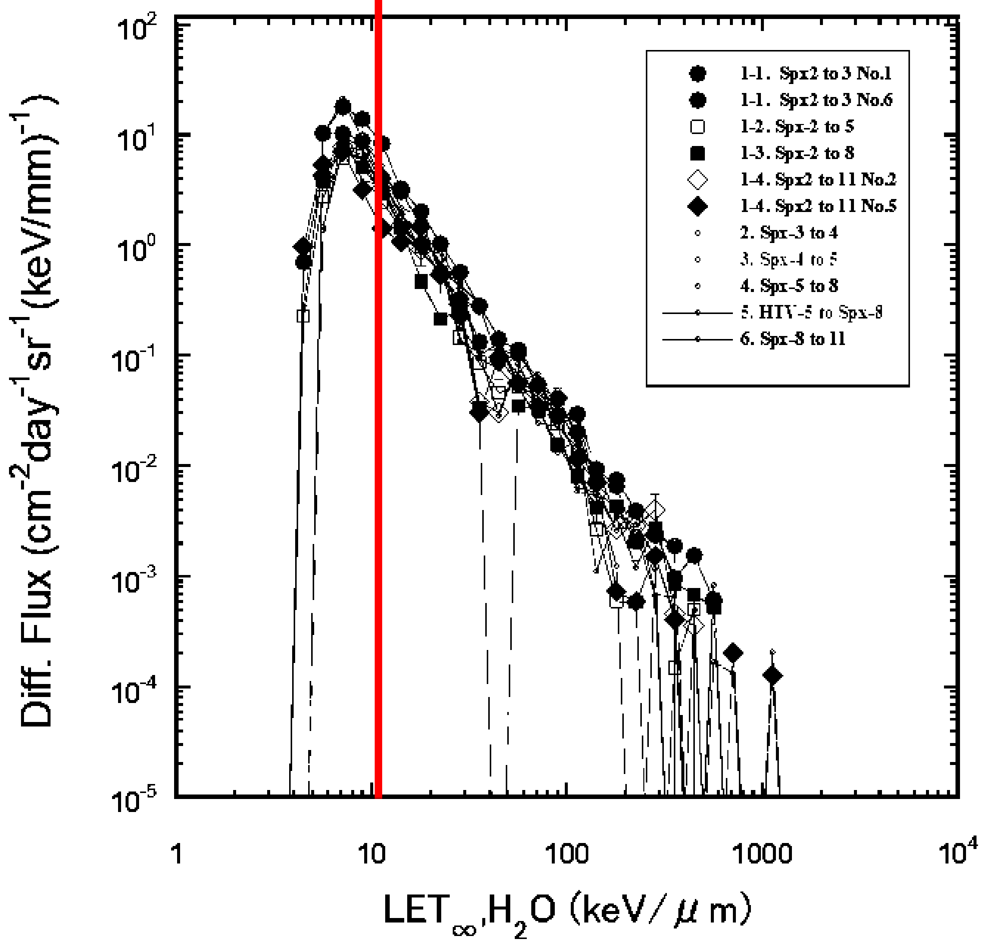



Comparison of the incidence of chromosomal aberrations of wild-type and histone H2AX gene heterozygous-deficient ES cells on the ground (BU) and on the ISS (MELFI) chromosomes were analyzed by FISH method.

The wild-type embryonic stem (ES) cells showed no differences in chromosomal aberrations between the ground control and ISS exposures. However, we detected an increase of chromosome aberrations in radio-sensitized histone H2AX heterozygous-deficient mouse ES cells and found that the rate of increase against the absorbed dose was 1.54-fold of proton irradiation.

# LET Distribution of Particles Detected by PADLES

Total 545 mGy (96%) | 25 mGy (4.4%)

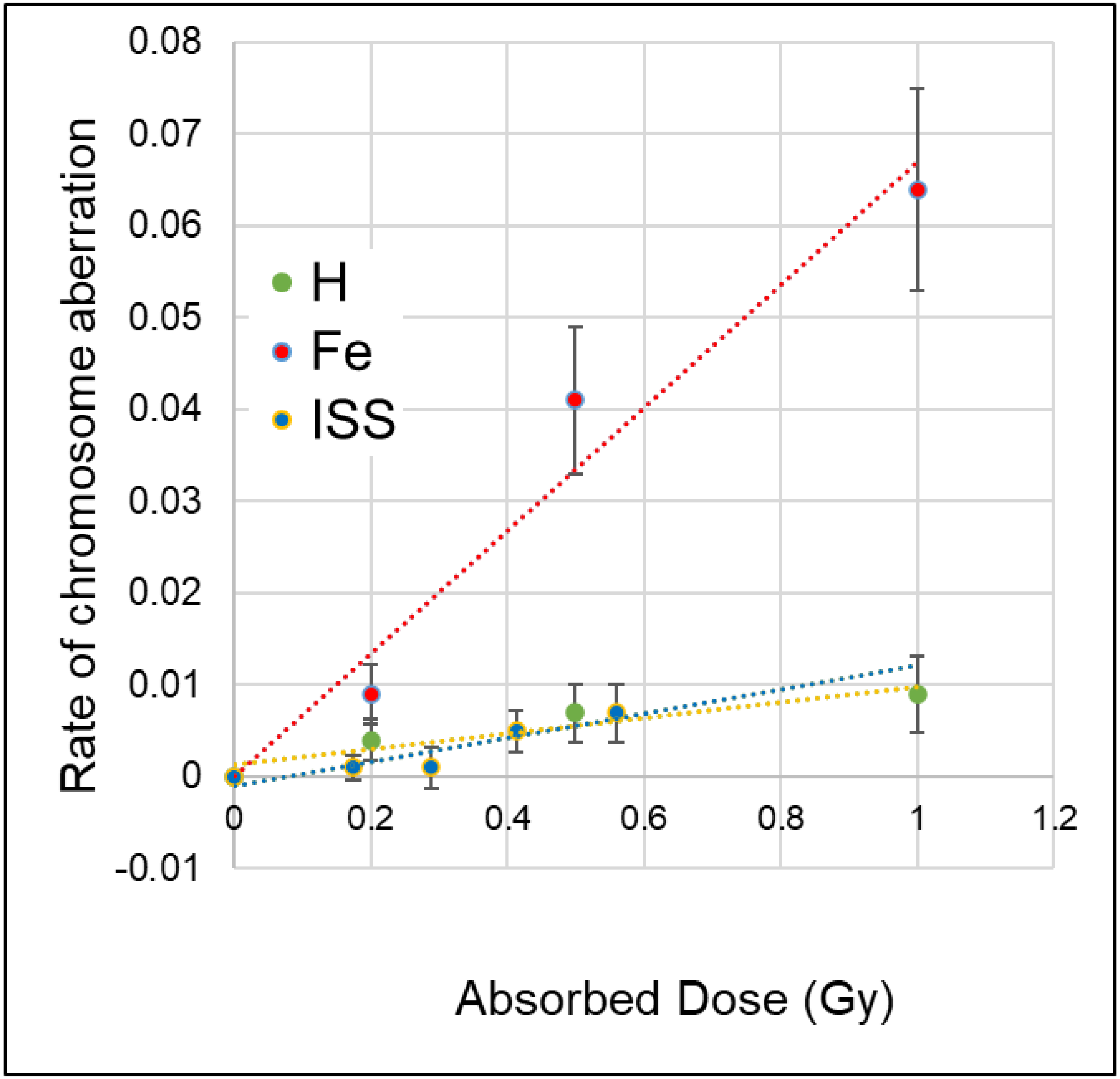



**LET distribution of particles as measured by PADLES**

Lower LET particles (< 10 keV /micron) contributed to 96% of the dose and

Higher LET particles (> 10 keV/micron) contributed to 4% of the total dose.

**Morita et al., 2021**
doi/10.24544/ocu.20210401-001

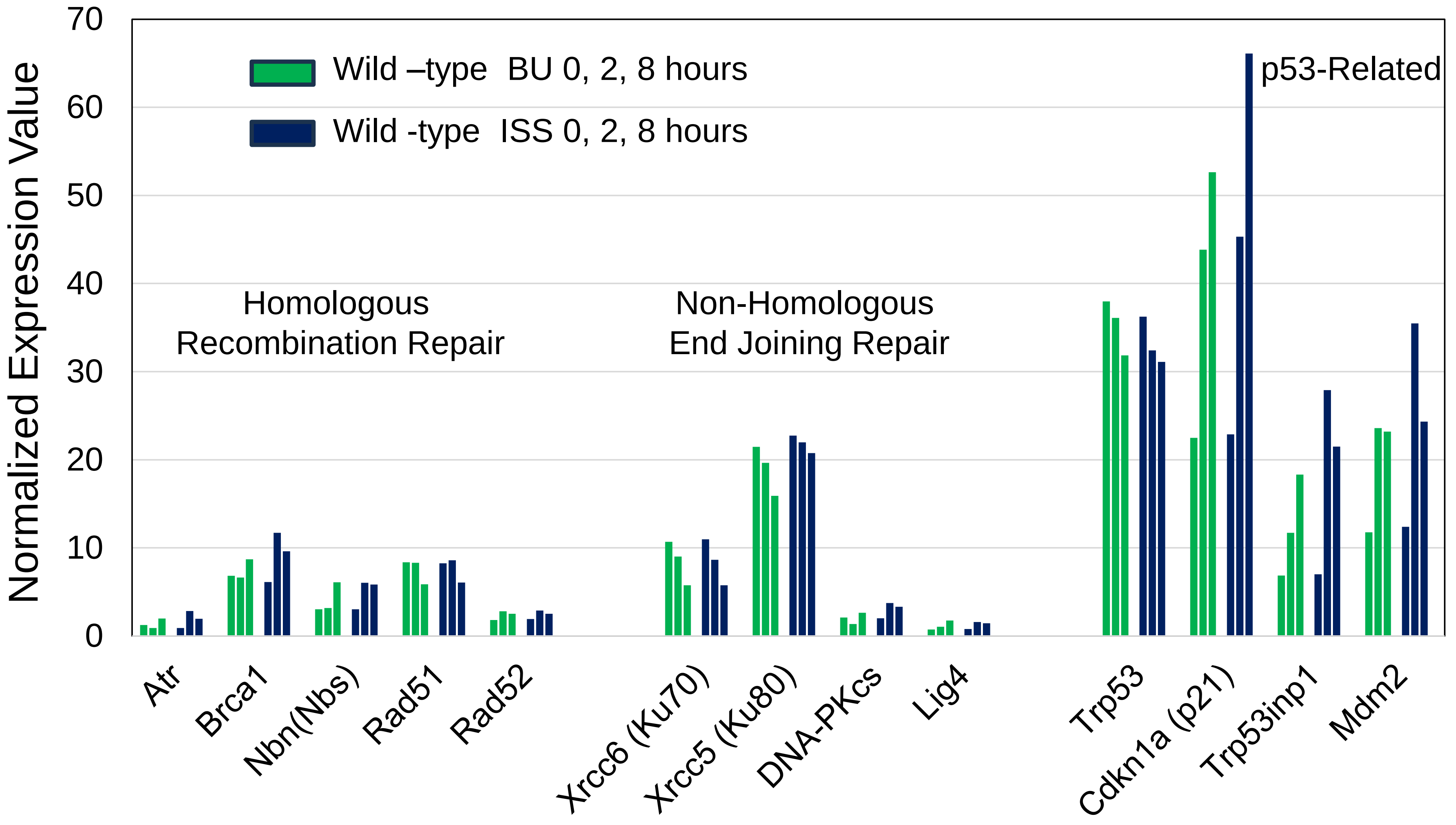



**Fe-ion beam**
500 MeV/n
LET 218 keV/µm

**Proton beam**
230 MeV
LET 0.415 keV/µm

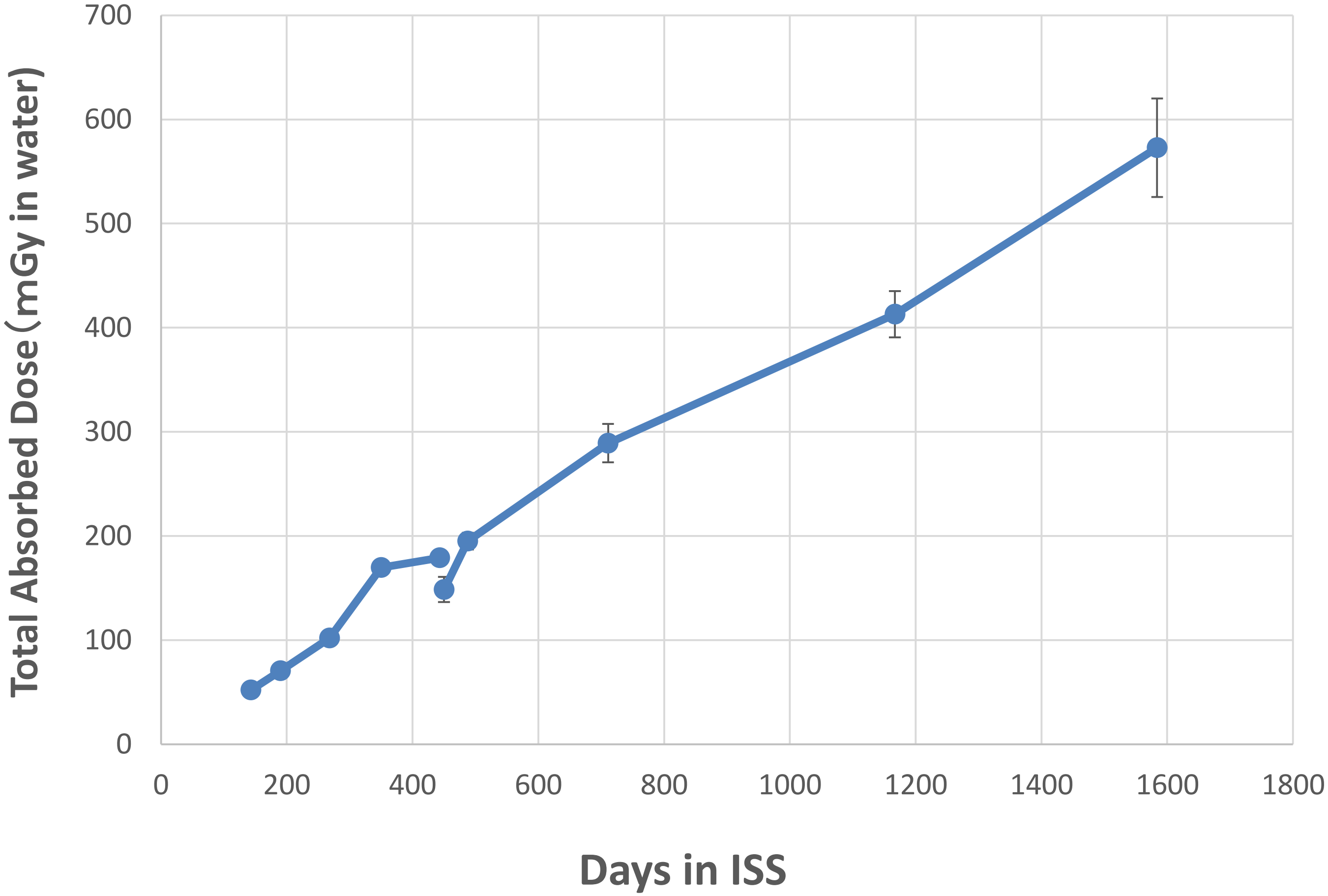
Yoshida, K. et al. *Heliyon 8(8)*, e10266. 2022

# Expression of DNA Repair Genes on ISS and Ground(BU)




Yoshida K. et al., *Int J Mol Sc*i; *25 (6)*

# Total Absorbed Dose [mGy in water]




Nagamatsu et al., JAXA - 2020

# Chromosome Aberration Studies on ISS: 2012-2022

Morita (JAXA) / Cucinotta (NASA) (PIs)

A CELL Press 2022 Publication

***Heliyon*** **8, no. 8 (2022) e10266**

Cell PRESS

# Dr. Morita (JAXA) and Dr. Cucinotta (NASA) – A Study on ISS

*Published in 2022 and Recognized as a NASA Science Discovery on ISS*

Heliyon 8 (2022) e10266

Contents lists available at ScienceDirect

**Heliyon**

journal homepage: www.cell.com/heliyon

Research article

## Comparison of biological measurement and physical estimates of space radiation in the International Space Station

Kayo Yoshida [a], Megumi Hada [b], Akane Kizu [a], Kohei Kitada [a], Kiyomi Eguchi-Kasai [c], Toshiaki Kokubo [c], Takeshi Teramura [d], Sachiko Yano [e], Hiromi Hashizume Suzuki [f], Hitomi Watanabe [g], Gen Kondoh [g], Aiko Nagamatsu [e], Premkumar Saganti [b], Francis A. Cucinotta [h], Takashi Morita [a,*]

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[b] *Radiation Institute for Science and Engineering, Prairie View A&M University, TX, USA*
[c] *QST National Institute of Radiation Sciences (NIRS), Chiba, Japan*
[d] *Kindai University, Faculty of Medicine, Osaka, Japan*
[e] *Japan Aerospace Exploration Agency (JAXA), Tsukuba, Japan*
[f] *Japan Space Forum (JSF), Tokyo, Japan*
[g] *Kyoto University, Institute for Frontier Medical Sciences, Kyoto, Japan*
[h] *University of Nevada, Las Vegas, NV, USA*

Heliyon 8 (2022) e10266

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

- ISS Study - This work is a result of experiments on board the ISS from 2012-2022 spanning over 10 years and 10 Expeditions
  - Dr. Morita, JAXA-Japan and Dr. Cucinotta, NASA-USA as the PIs
  - From 2016, through our CRI / RaISE, we analyzed samples and data from ISS and contributed to this unique work.
- ISS Discovery – Included for 2022
  - Results from the ISS provide new contributions to the body of scientific knowledge in the physical sciences, life sciences, and Earth and space sciences to advance scientific discoveries in multi-disciplinary ways.
- ISS Publication - This publication made its presence on ISS Research Explorer's Page of the NASA Website (2022)
  - As part of the ongoing radiation biology / biotechnology research work - Stem Cells (nasa.gov)

# Few Thoughts

- From these results, in contrast to the expression of homologous recombination repair genes such as RecA in prokaryotic cells, and Rad51 in yeast, and unicellular eukaryote (Ascomycete) which are induced in response to radiation.
- In higher eukaryotes such as mouse ES cells, DNA damage does not immediately induce the transcription of repair genes, but rather activates proteins such as ATM, followed by phosphorylation of p53 protein.
- Recently, it has been reported that the strong radiation resistance of tardigrades, which are classified as an invertebrate Panarthropod, is due to the dramatic induction of DNA repair genes such as Rad51 and ERCC6 (Ku70).

# References


- NASA: Stem Cells - Study on the Effect of Space Environment to Embryonic Stem Cells to Their Development. https://www.nasa.gov/mission/station/research-explorer/investigation/?#id=871

- 2024:Yoshida K, Hada M, Hayashi M, Kizu A, Kitada K, Eguchi-Kasai K, Kokubo T, Teramura T, Suzuki HH, Watanabe H, Kondoh G, Nagamatsu A, Saganti PB, Muratani M, Cucinotta FA, Morita T. Transcriptome analysis by RNA sequencing of mouse embryonic stem cells stocked on International Space Station for 1584 days in frozen state after culture on the ground. International Journal of Molecular Sciences. 2024 January; 25(6): 3283. DOI: 10.3390/ijms25063283.PMID: 38542258.

- 2022: Yoshida K, Hada M, Kizu A, Kitada K, Eguchi-Kasai K, Kokubo T, Teramura T, Yano S, Suzuki HH, Watanabe H, Kondoh G, Nagamatsu A, Saganti PB, Cucinotta FA, Morita T. Comparison of biological measurement and physical estimates of space radiation in the International Space Station. Heliyon. 2022 August 1; 8(8): e10266. DOI: 10.1016/j.heliyon.2022.e10266.PMID: 36061033.

- 2016: Ohnishi T. Life science experiments performed in space in the ISS/Kibo facility and future research plans. Journal of Radiation Research. 2016 August 16; 57(S1): i41-i46. DOI: 10.1093/jrr/rrw020.PMID: 27130692.

- 2010: Yoshida K, Yoshida S, Eguchi-Kasai K, Morita T. Study of the effects of space radiation on mouse ES cells. Biological Sciences in Space. 2010 April; 24(1): 11-15. DOI: 10.2187/bss.24.11.

- 2024: Morita et al., in PRESS
- 2024 : Yoshida et al., in PRESS
- 2024: Hada et al., in PRESS

# NEUTRONS

Studies at LANL


Mutation Research 701 (2010) 67–74

Contents lists available at ScienceDirect

Mutation Research/Genetic Toxicology and Environmental Mutagenesis

journal homepage: www.elsevier.com/locate/gentox
Community address: www.elsevier.com/locate/mutres

ELSEVIER

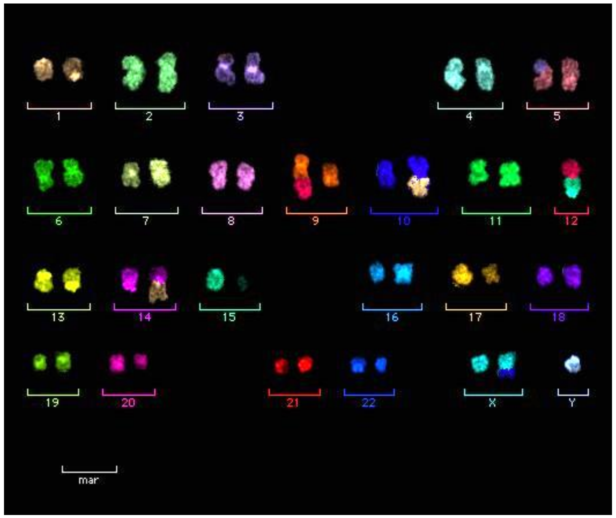
# mBAND analysis of chromosome aberrations in human epithelial cells induced by γ-rays and secondary neutrons of low dose rate

M. Hada[a,b], B. Gersey[c], P.B. Saganti[c], R. Wilkins[c], F.A. Cucinotta[a], H. Wu[a,*]

[a] NASA Johnson Space Center, Houston, TX 77058, USA
[b] Universities Space Research Association, Houston, TX 77058, USA
[c] Prairie View A&M University, Prairie View, TX 77446, USA

# Chromosome painting with Multicolor fluorescence in Situ Hybridization

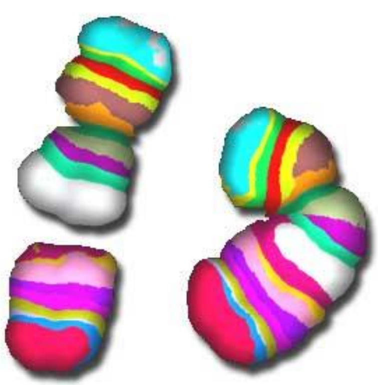
mFISH




Multicolor Fluorescence *in situ* Hybridization

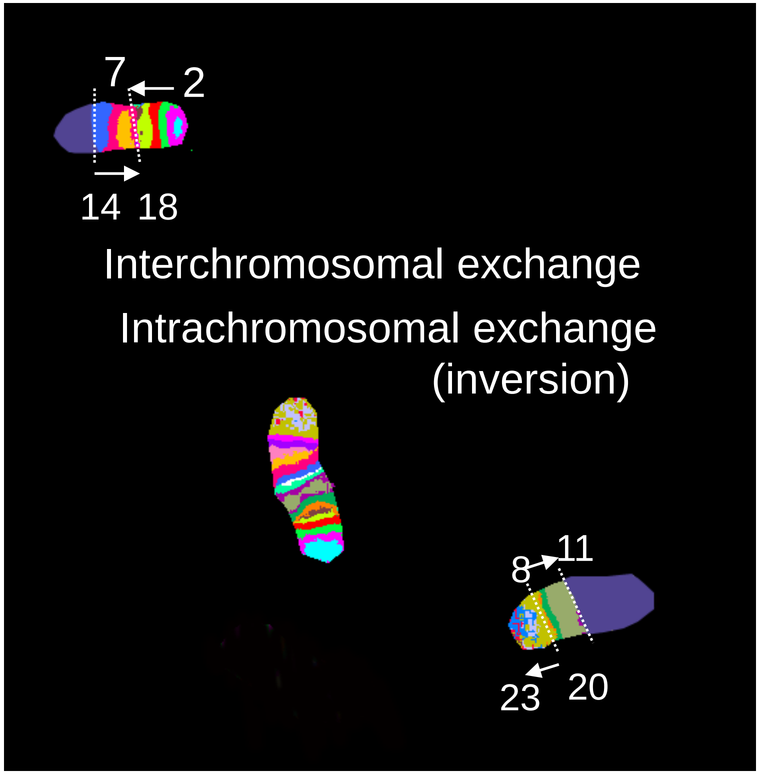
- simultaneous presentation of all 24 different human chromosomes with one single hybridization
- analysis of hidden or complex chromosome aberrations
- composition of marker chromosomes

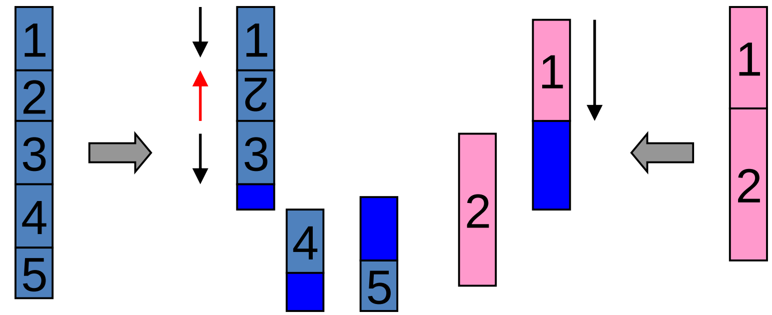
mBAND



Multicolor Banding *in situ* Hybridization

- color banding pattern along one chromosome
- higher level of precision within one chromosome
- detection of intrachromosomal rearrangements
- detection of break points


7
2
14 18
Interchromosomal exchange
Intrachromosomal exchange
(inversion)
8
11
23
20


1
2
3
4
5
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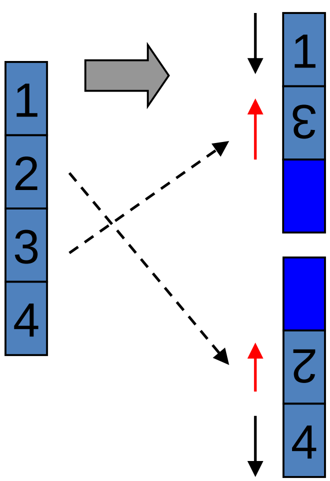
5
2
1
1
2


1
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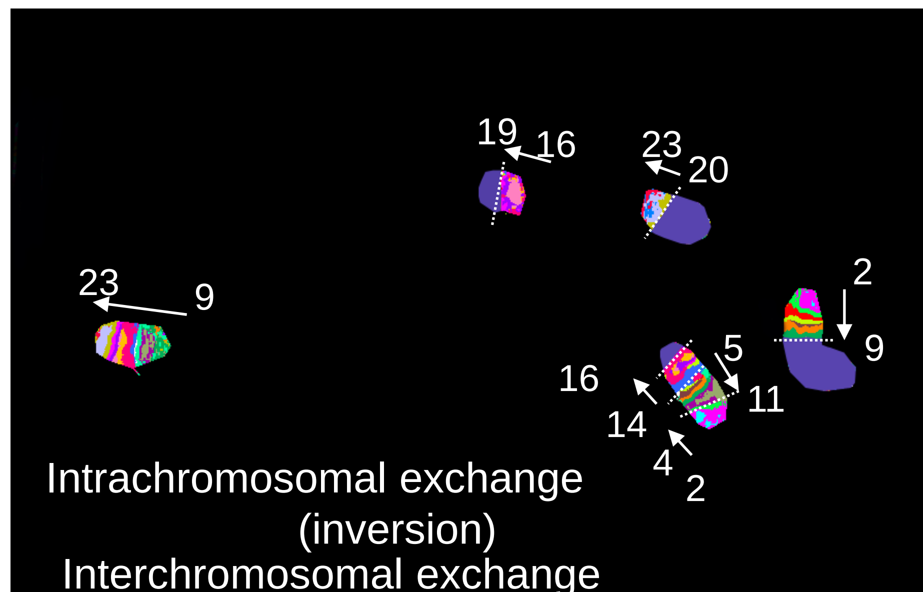
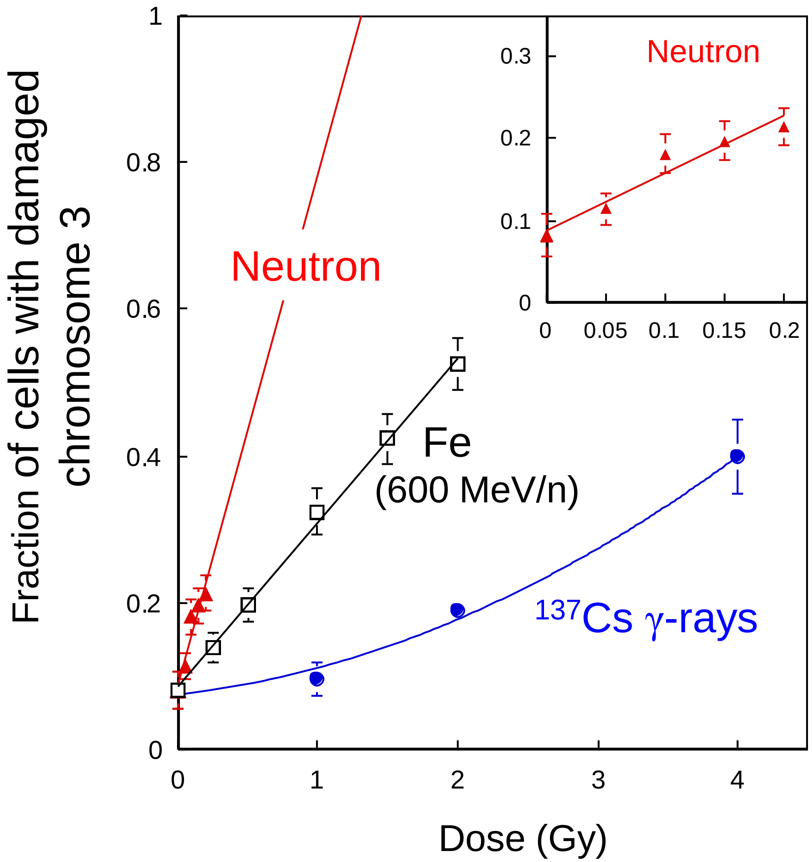

19
16
23
20
23
9
2
9
5
16
11
14
4
2
Intrachromosomal exchange
(inversion)
Interchromosomal exchange

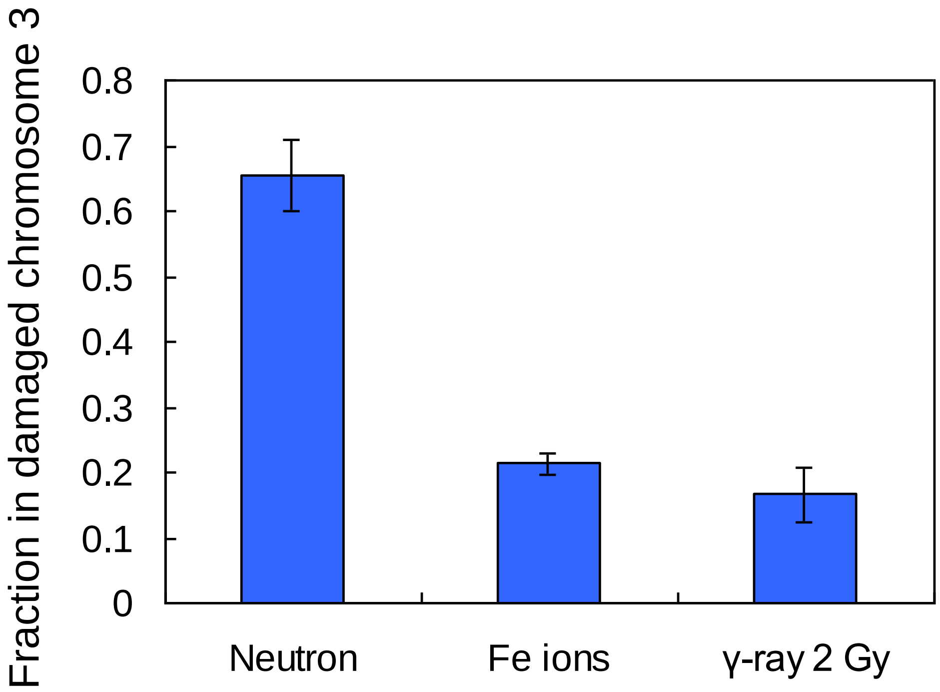
# *Induction of chromosome 3 aberration in human cells by Neutron, Fe-ions or $\gamma$-rays*




RBE for 20% of cells with damaged chromosome 3
Fe: 4.5
Neutron: 14.7

*Fe-ions induced more aberrations in chromosome 3 compared to $\gamma$-rays, and neutron induced more aberration than Fe ions.*

# *Induction of terminal deletion in human chromosome 3 by neutron, Fe ions or γ-rays irradiation*




*Neutron induced more terminal deletion compare to Fe ions and γ-rays irradiation.*

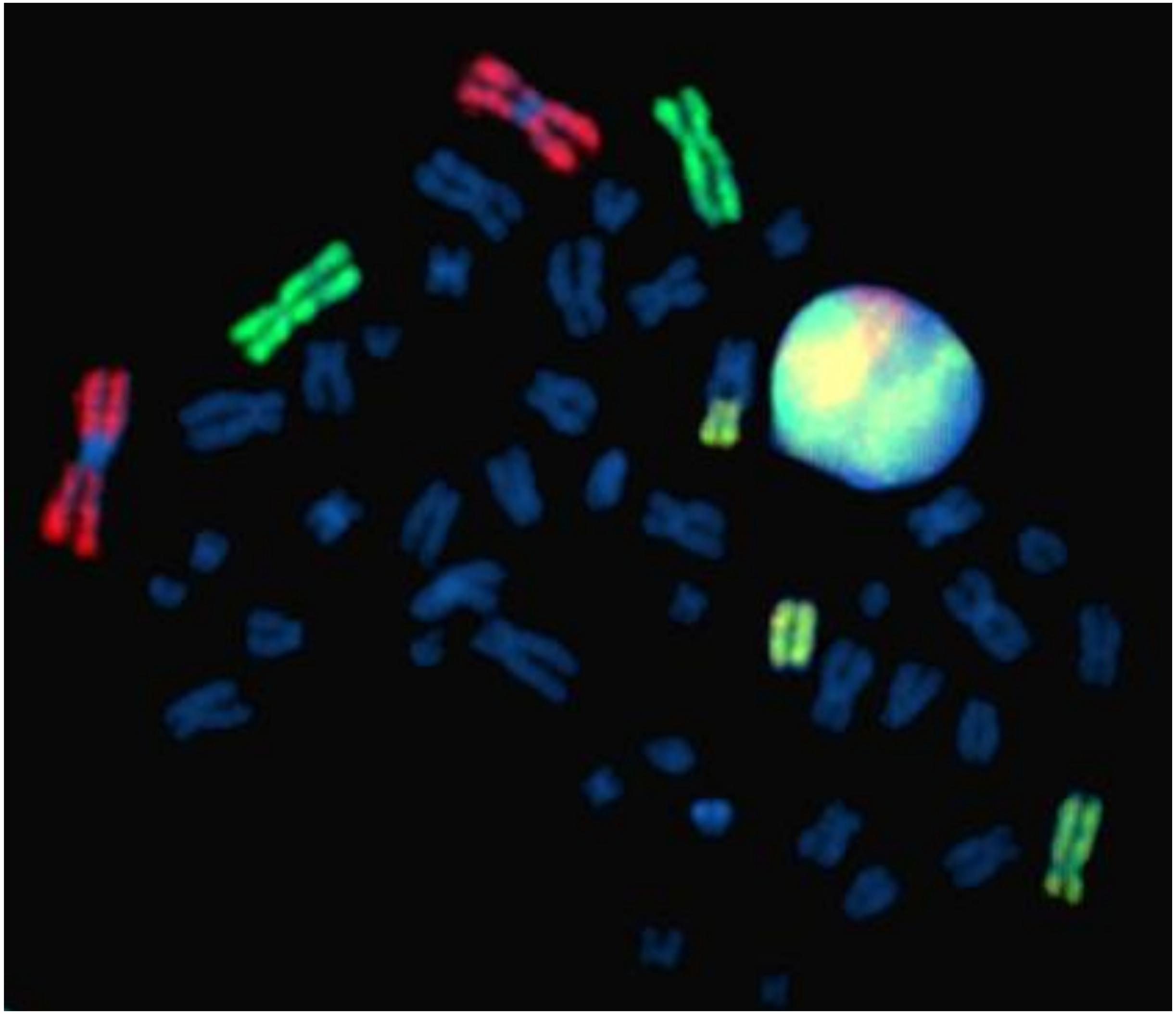
# Microgravity + Radiation

SYNEGESTIC EFFECTS

2023

ICRR 2023
Montréal, Quebec
August 29, 2023
Hada / Saganti

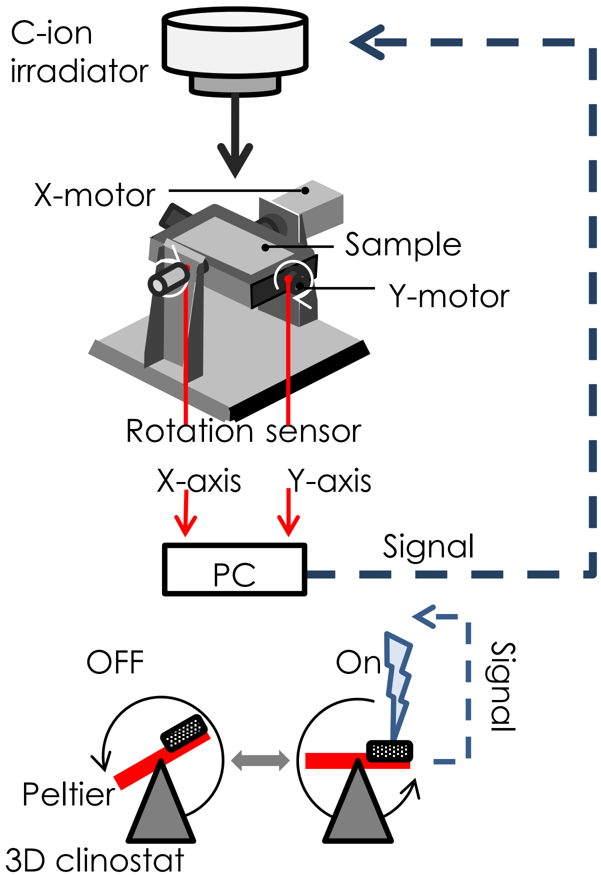
**S25-05**

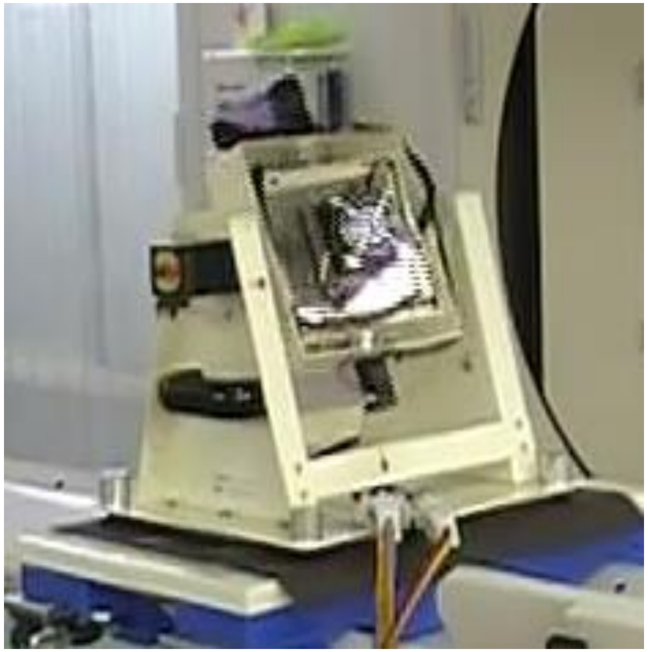


RADIATION INSTITUTE FOR SCIENCE & ENGINEERING

# 3D clinostat with C-ion system



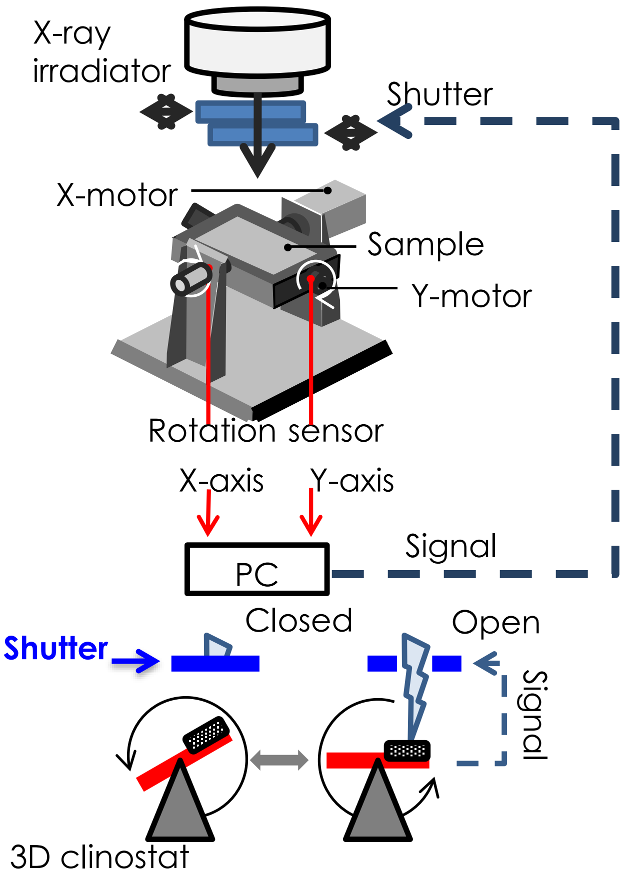


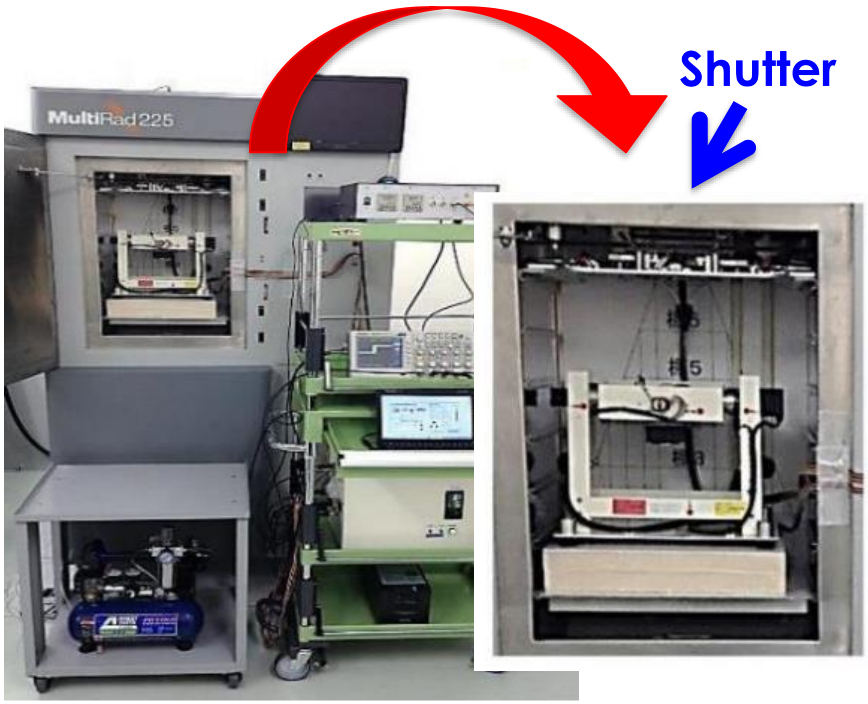



290 MeV/n, 50 keV/m, ca 0.03 Gy/min
(Gunma University Heavy Ion Medical Center,
Maebashi, Japan)

*Ikeda H et al. Life Sci Space Res 2017; 12:51-60*

# 3D clinostat with X-ray system

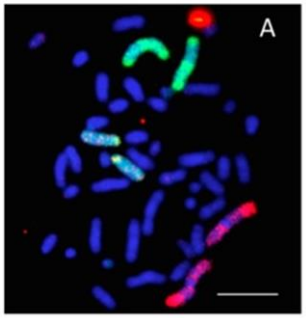


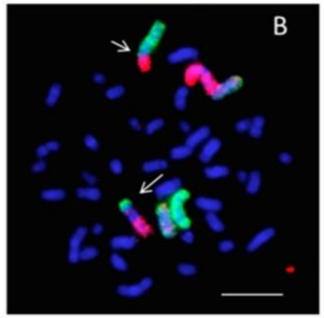

200 kV, 14.6 mA, 0.3 mm aluminum filter ca 0.03 Gy/min
(MultiRad225: Faxitron Bioptics, LLC, Tucson, AZ, USA)

*Ikeda H et al. Biol Sci Space 2016; 30:8-16*

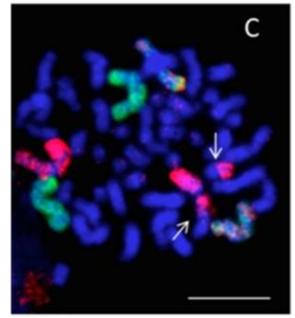
## 3-color fluorescent *in situ* hybridization method



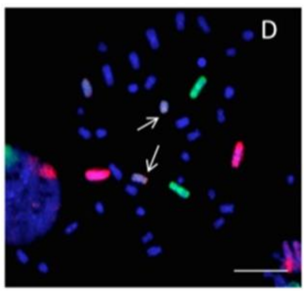

Normal



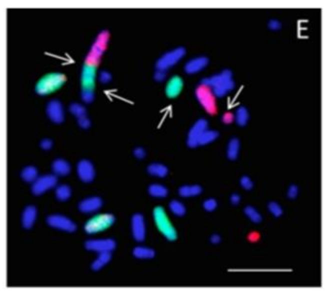

Simple exchange (1 & 2)



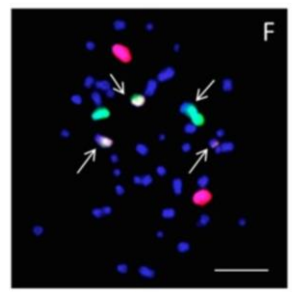

Simple exchange (1 & other)




Break in chromosome 4




Complex exchange (1 and 2 & other)

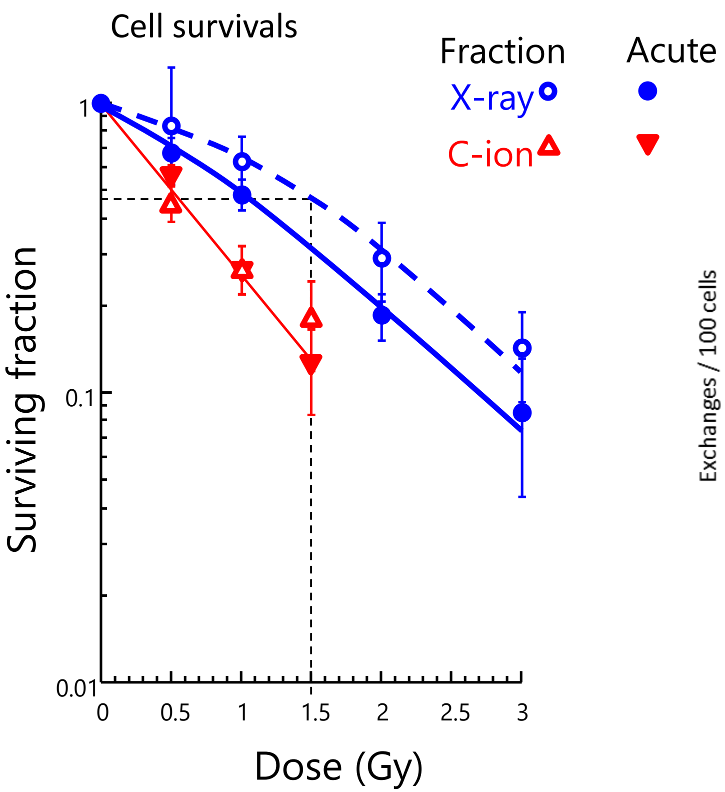


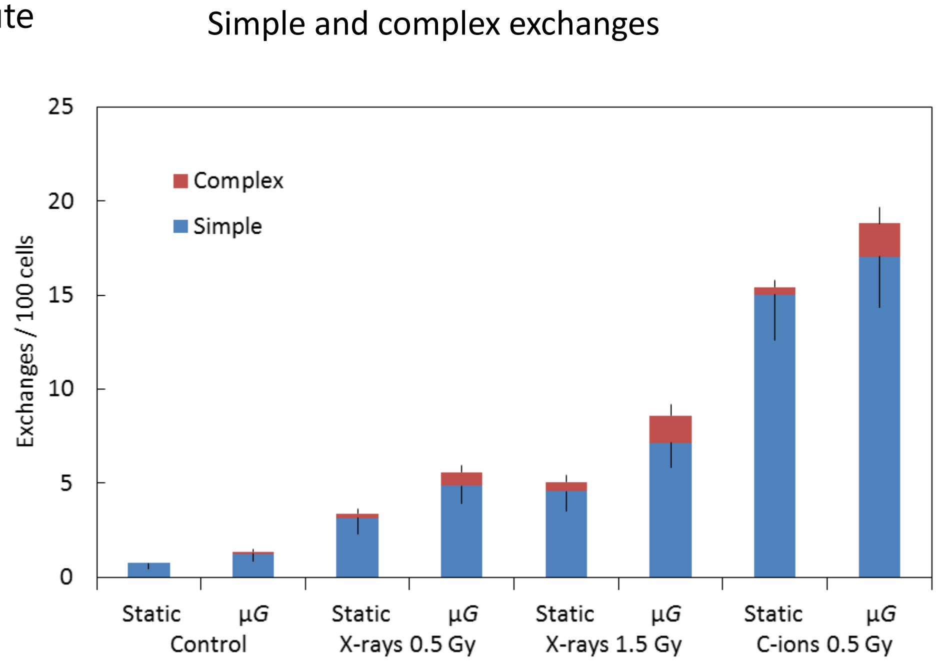

Complex exchange (2, 4 & other)

Chromosomes 1: red
Chromosomes 2: green
Chromosomes 4: yellow

Complex exchanges: An exchange involved a minimum of three breaks in two or more chromosomes
Simple exchanges: Two breaks in two chromosomes (dicentrics and translocations)

# Cell survival and chromosome aberration - Fibroblasts

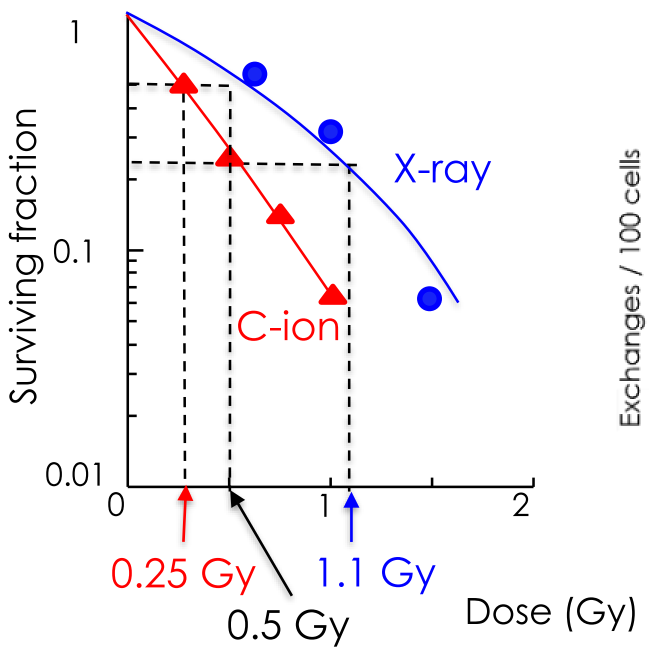


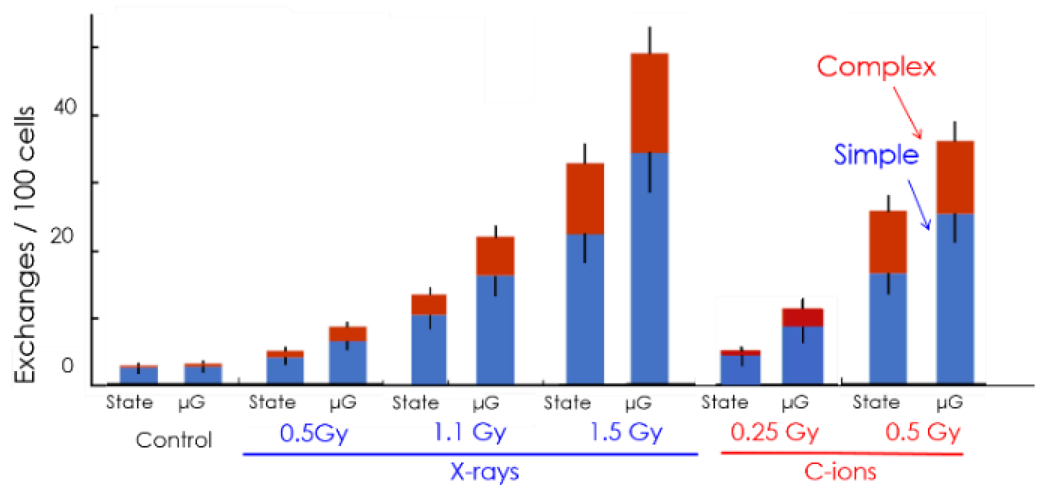

*Hada M et al. Int. J. Mol. Sci. 2019; 20:43*

# Cell survival and chromosome aberration – Lymphoblast TK6

Cell Survival




Simple and complex exchanges



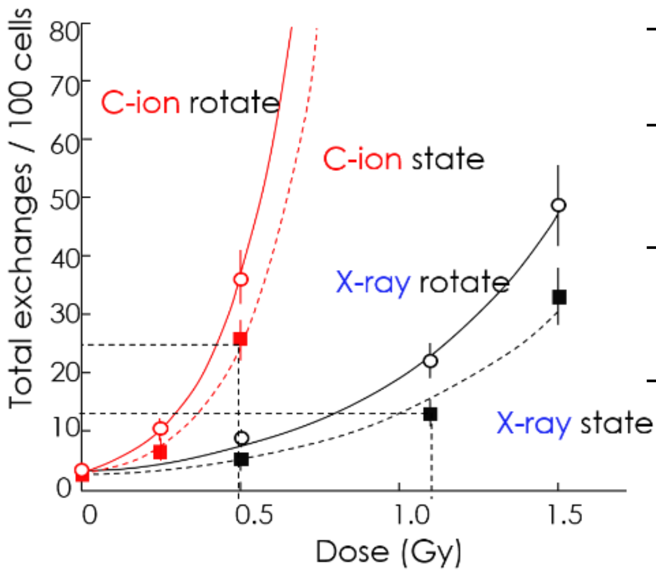

Simulated μG + Irradiation

Higher frequency of CA

*Yamanouchi S et al. Life 2020;10:0187*

# Statistical analysis – CA Lymphoblast TK6

Total Chromosome aberrations



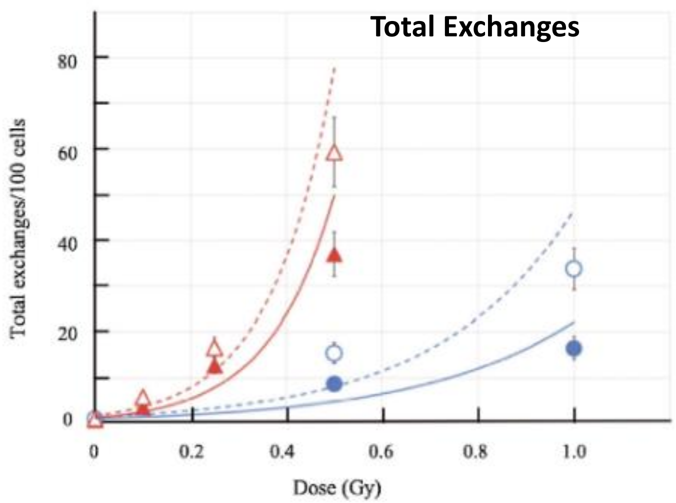

The logistic regression analysis of the effect of radiation and gravity on total exchanges.

| Radiation Type | | Coefficient | Standard error of coefficient | *p*-value | Odd ratio | 95% CI for OR | |
|---|---|---|---|---|---|---|---|
| | | | | | | Lower | Upper |
| X-ray | Dose | 1.906 | 0.136 | $2.12 \times 10^{-44}$ | 6.727 | 5.150 | 8.789 |
| | Gravity | 0.491 | 0.132 | $2.04 \times 10^{-4}$ | 1.635 | 1.261 | 2.118 |
| | Constant | -4.826 | 0.171 | $3.30 \times 10^{-174}$ | | | |
| C-ion | Dose | 5.218 | 0.447 | $1.85 \times 10^{-31}$ | 184.559 | 76.821 | 443.396 |
| | Gravity | 0.397 | 0.156 | $1.1 \times 10^{-2}$ | 1.487 | 1.487 | 2.018 |
| | Constant | -4.787 | 0.193 | $4.75 \times 10^{-136}$ | | | |

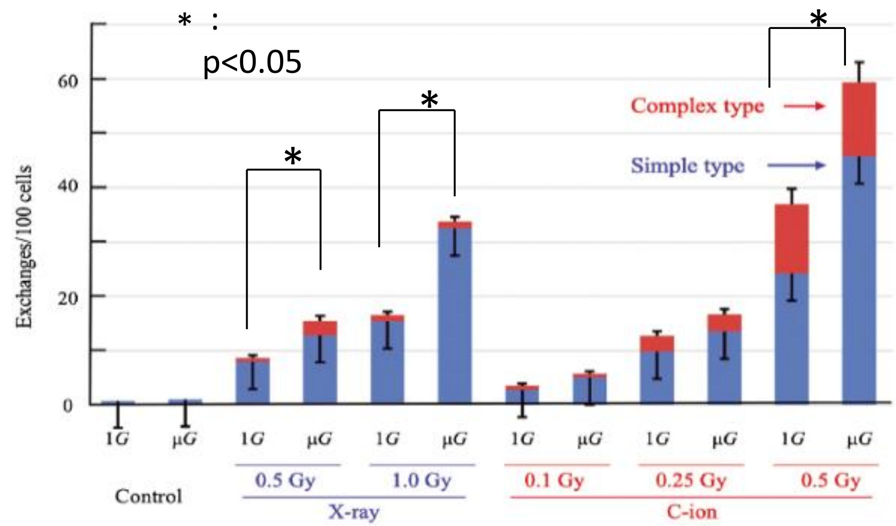
Both dose and gravity significantly contribute to total exchanges.

*Yamanouchi S et al. Life 2020;10:0187*

Chromosome aberration – Blood Lymphocytes




**Simple and Complex Exchanges**




**The logistic regression analysis of the effect of radiation dose and gravity on total exchanges**

| Radiation | Factor | Coefficient | SE* of coefficient | p-value | OR** | 95%CI*** for OR | |
|---|---|---|---|---|---|---|---|
| | | | | | | Lower | Lower |
| X-ray | Dose | 2.732 | 0.203 | $3.65\times10^{-41}$ | 15.370 | 10.318 | 22.895 |
| | Gravity | 0.760 | 0.150 | $4.00\times10^{-7}$ | 2.138 | 1.594 | 2.868 |
| | Constant | –5.247 | 0.178 | $1.85\times10^{-191}$ | | | |
| C-ion beam | Dose | 6.284 | 0.355 | $3.13\times10^{-70}$ | 535.886 | 267.397 | 1073.961 |
| | Gravity | 0.466 | 0.124 | $1.66\times10^{-4}$ | 1.594 | 1.250 | 2.031 |
| | Constant | –5.490 | 0.146 | $<1.00\times10^{-191}$ | | | |

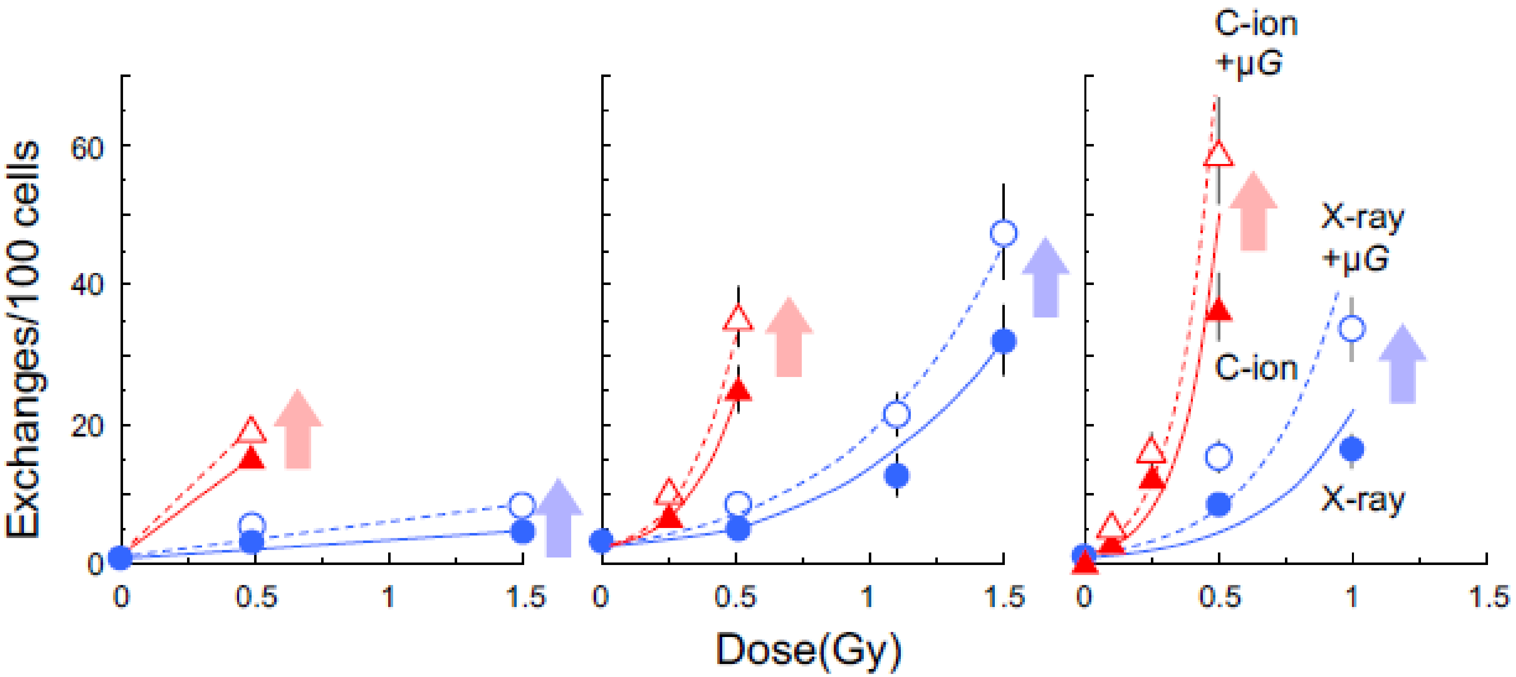
*SE, standard error; **OR, odds ratio; ***CI, confidence interval.

Both dose and gravity significantly contribute to total exchanges.

*Yamanouchi S et al.*
*Biol Sci Space 2021; 35:15-23*

# Comparison of cells

Fibroblast (1BR-hTERT) | Lymphoblastoid cells (TK6) | Blood lymphocytes

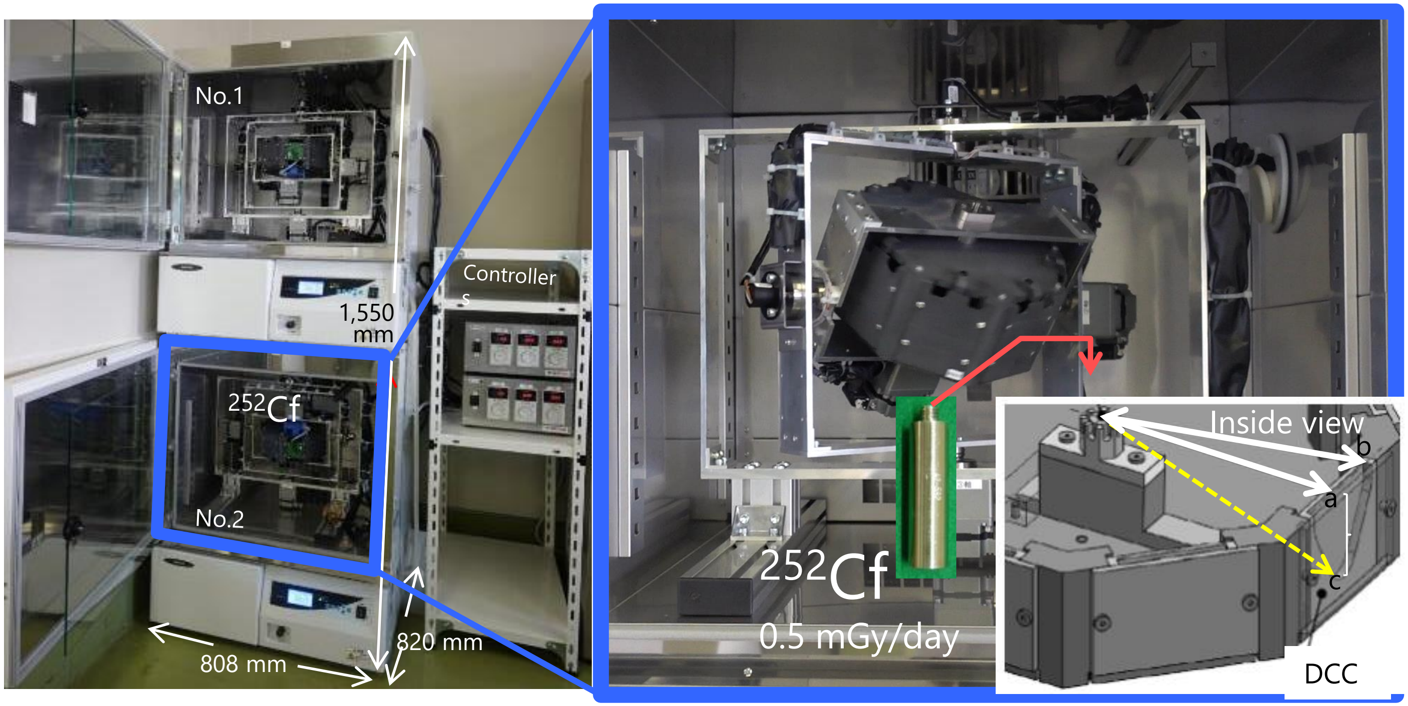


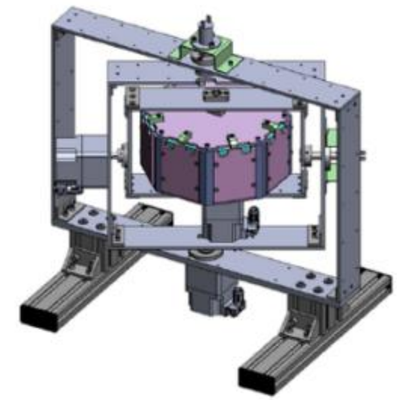

*Hada M et al. Int J Mol Sci 2019; 20:43*

*Yamanouchi S et al. Life 2020; 10:187*

*Yamanouchi S et al. Biol Sci Space 2021; 35:15-23*

# **SwiNG** **S**imulator of the environments on the Moon and Mars **wi**th **N**eutron-irradiation and **G**ravity-change

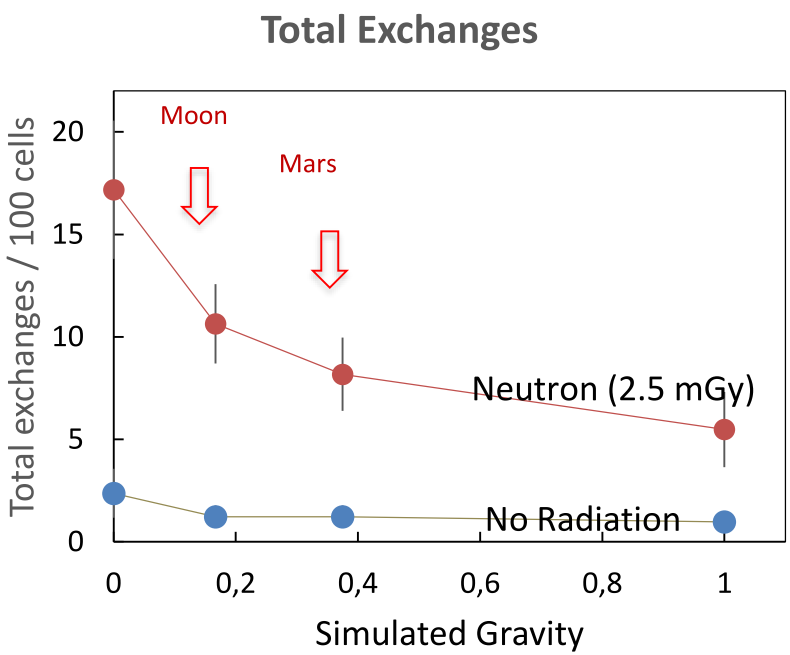


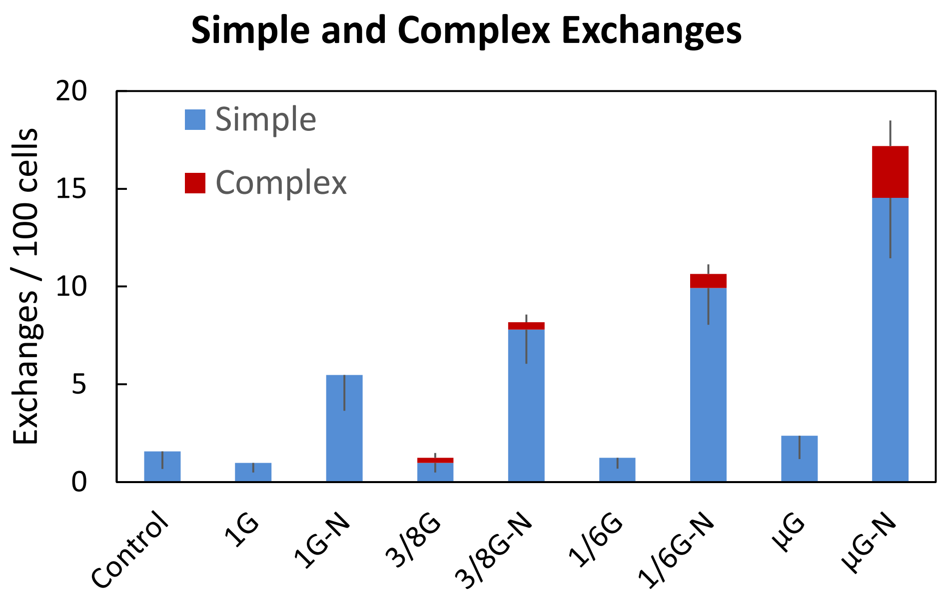



Takahashi A, *et al*. Life 10: 274, 2020

The X:Y ratios of clino-rotation were set at 11:13 rpm.
The rotary speed of motor 1 was 0-133 rpm (0-2*G*).

# Chromosome aberrations with low dose neutron exposure



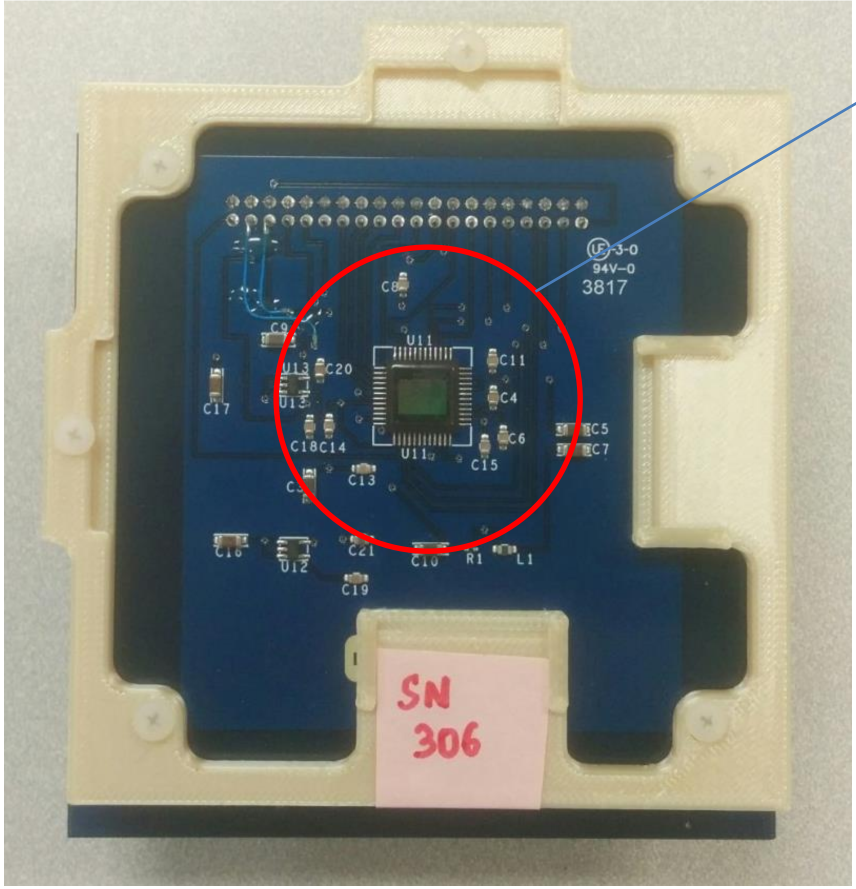

N: Neutron 0.5mGy/day x 5 days

Frequencies of CA induced by neutron exposure is depending on the gravity condition

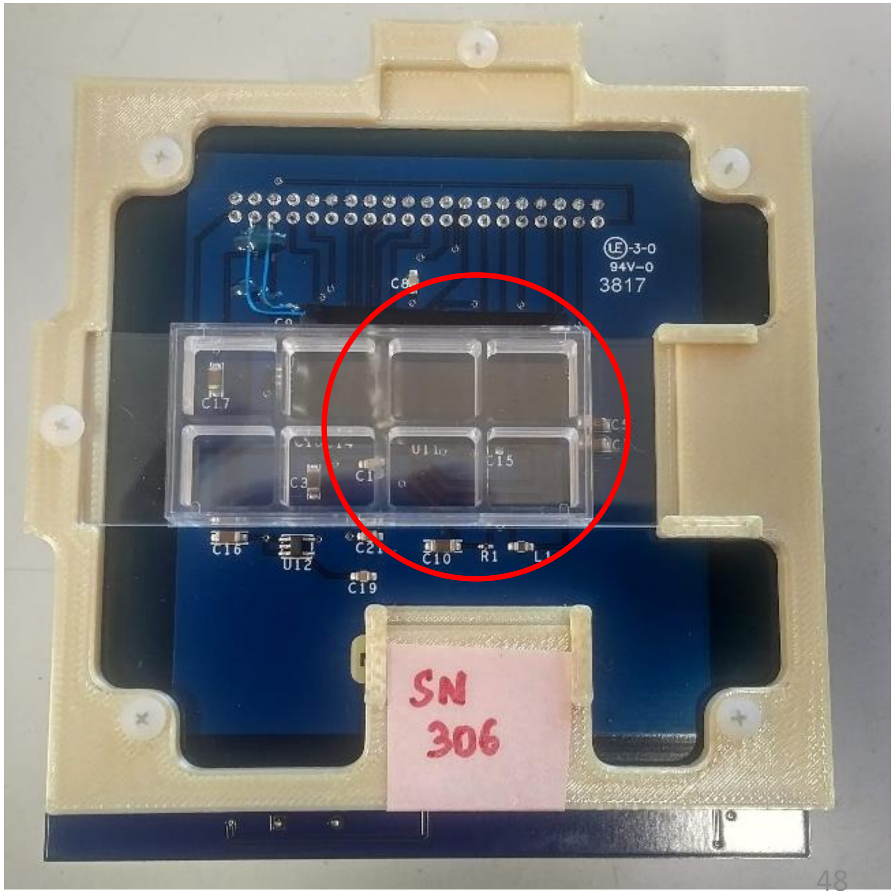
# OTHER BIOLOGICAL APPLICATIONS

Radiation Track Structure Detector

# Track Structure Detector




Sensor Dimensions: 0.644 cm (H) x 0.461 cm (V)
Active Pixels: 3664(H) x 2748(V); 10,068,672
Pixel Size: 1.67 x 1.67 µm



# Example - DNA damage foci and pixel image (Wang / Saganti)

- DNA damage foci
  - Live imaging  mCherry - 53BP1 in mouse hippocampal neuronal cells
  - Staining 53BP1 in mouse hippocampal neuronal cells
  - Zeiss  Fluorescent microscope at NSRL
  - Leica Confocal microscope at RaISE

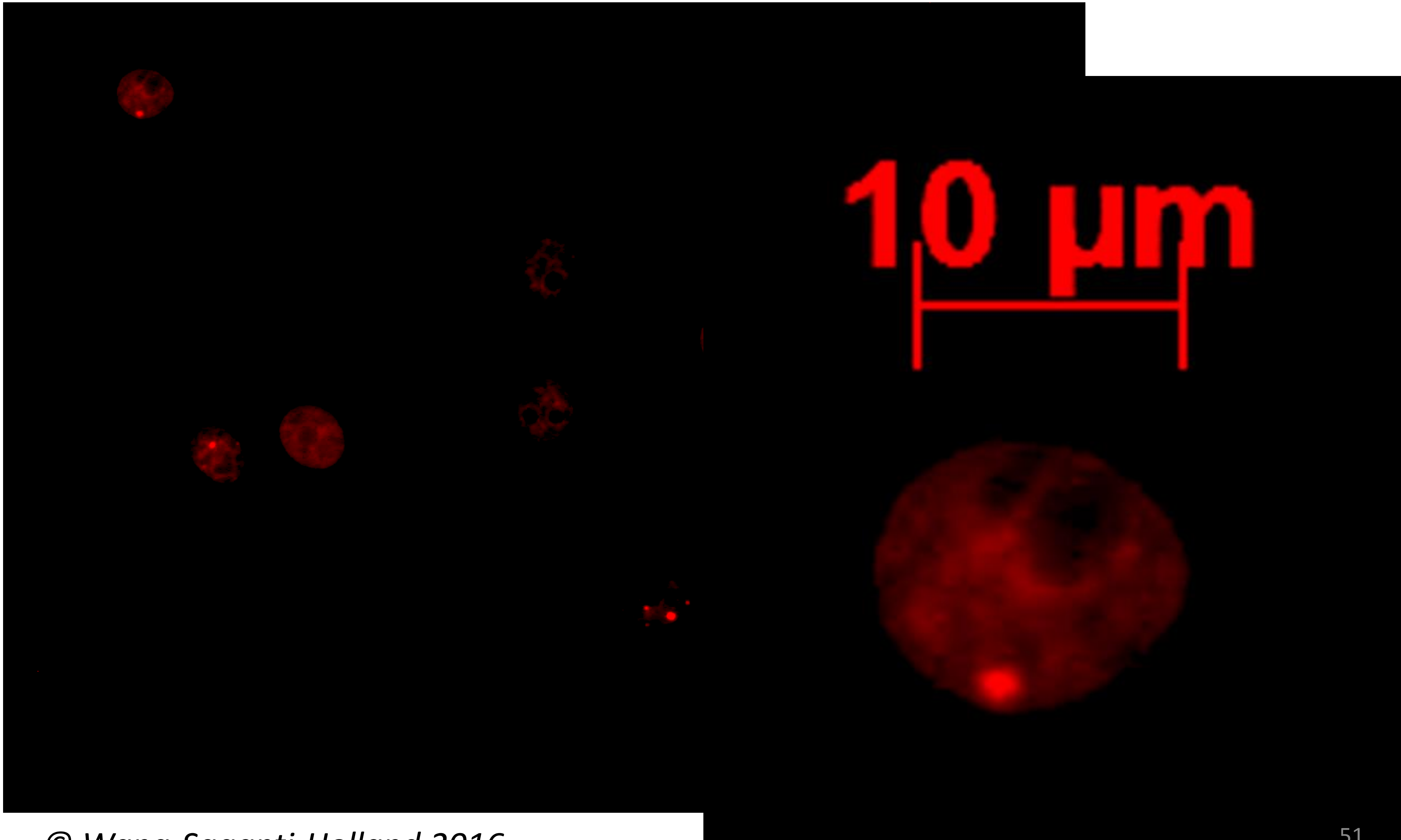
- Pixel image
  - 1.67 um/pixel
  - 10 um each pixel spot and 100 um pixel track

- Foci image
  - 0.16 um/pixel
  - about 1 um each focal spot and 10 um foci track

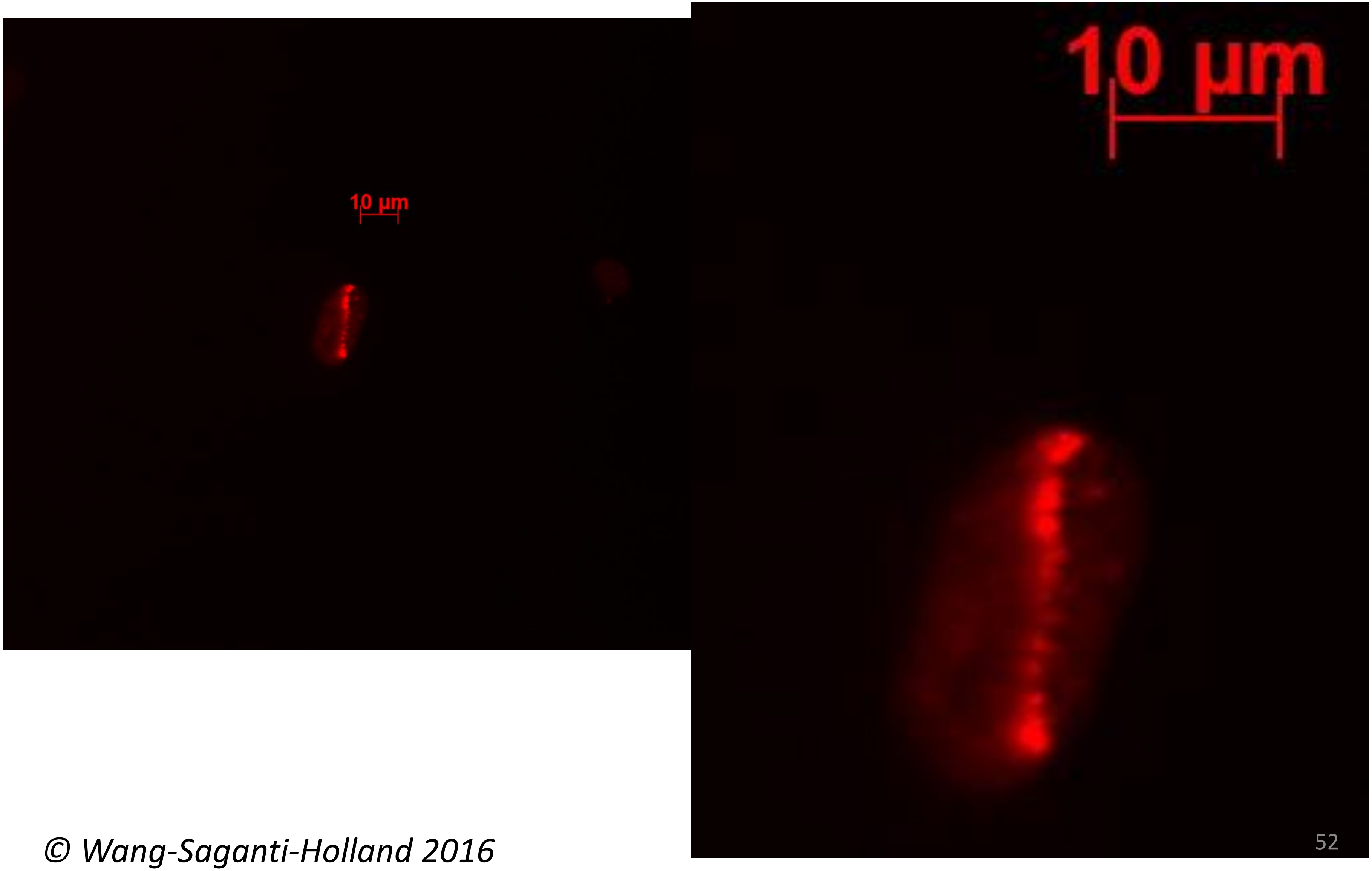
# EXPERIMENTS WITH CARBON IONS

# BNL (USA)
# HIMAC (JAPAN)

# C-300 MeV: Detector along the beam line (90° alignment)
# Beam: Dose-Rate = 1 cGy/min, Total Dose = 2cGy

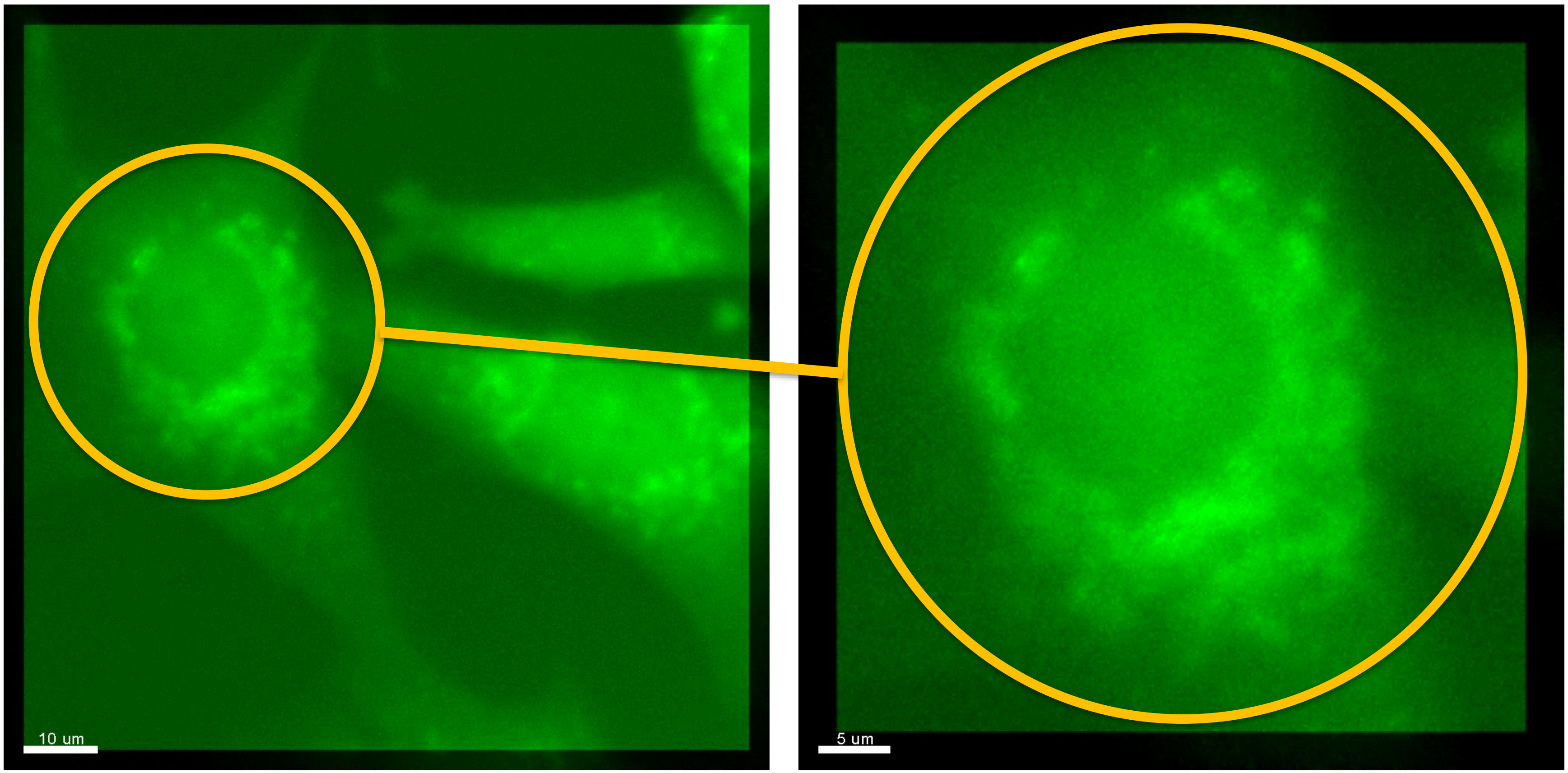


# C-300 MeV: Detector along the beam line (0° alignment)
# Beam: Dose-Rate = 1 cGy/min, Total Dose = 2cGy



# Mouse Hippocampal neuronal cells (HT22) and Radiation Particle Trajectory (C ions, LET = 50 keV/um)

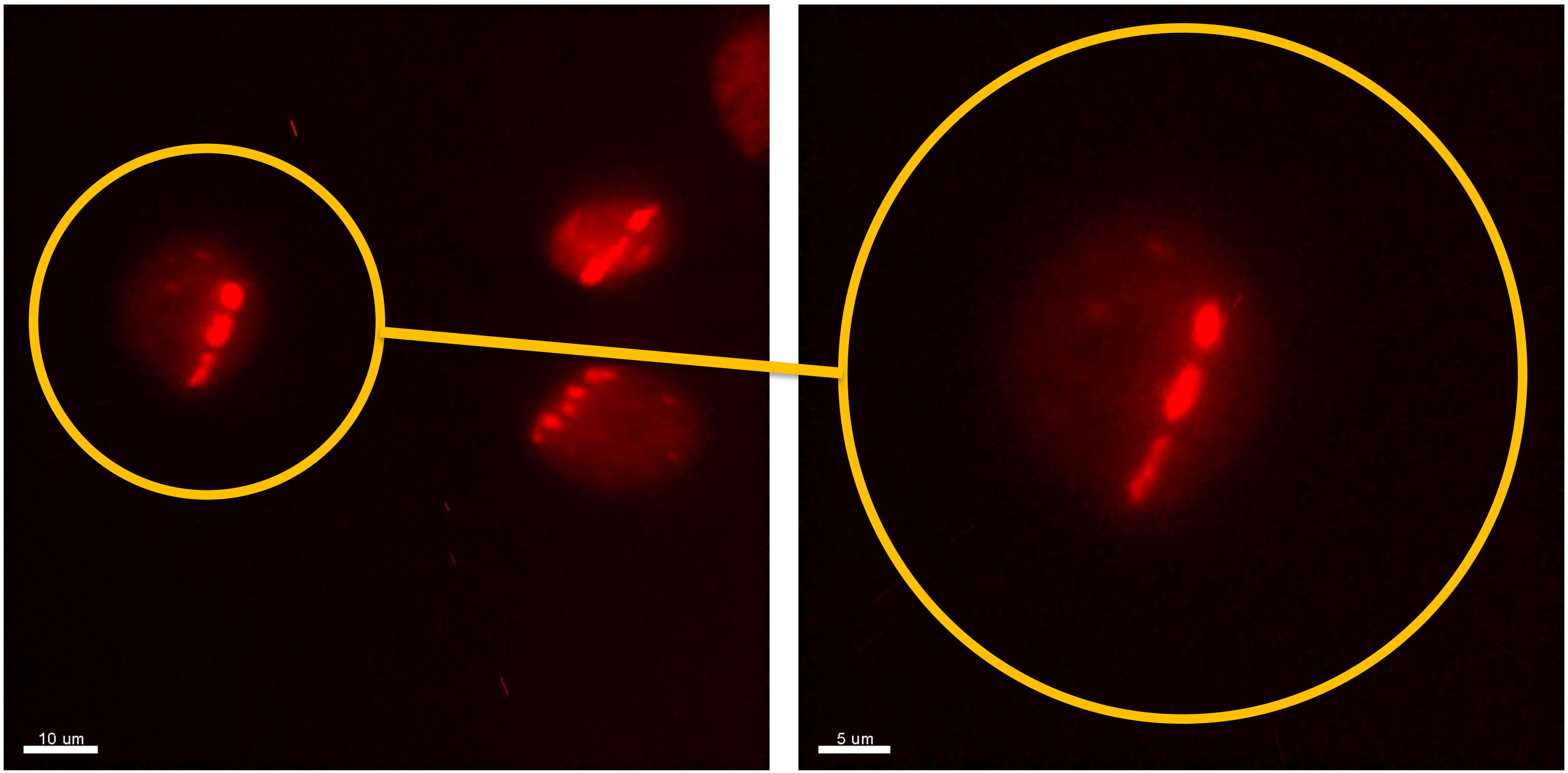
# (GFP-LC3)




*© Inage Credit – Leica SP8 Confocal System at CRI / RaISE*

# Mouse Hippocampal neuronal cells (HT22) and Radiation Particle Trajectory (C ions, LET = 50 keV/um)

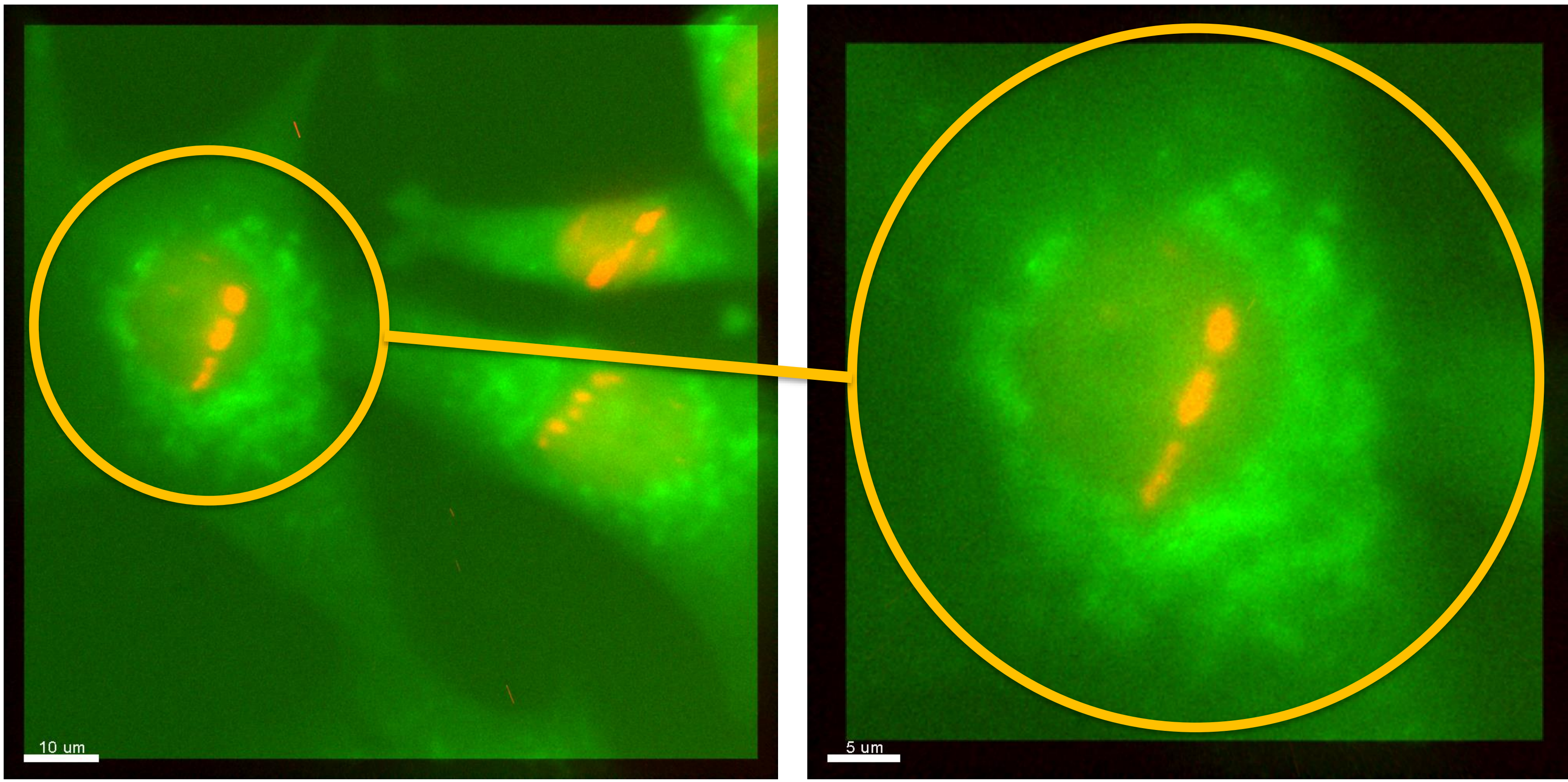
# (mCherry-53BP1)




*© Inage Credit – Leica SP8 Confocal System at CRI / RaISE*

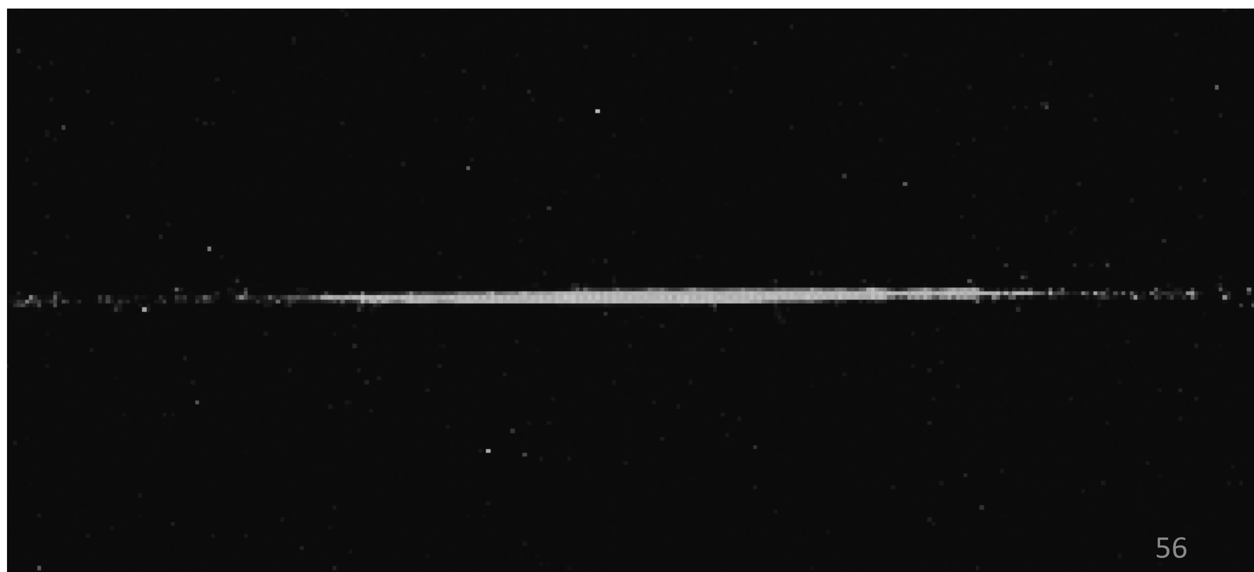
# Mouse Hippocampal neuronal cells (HT22) and Radiation Particle Trajectory (C ions, LET = 50 keV/um)

# [(GFP-LC3) + (mCherry-53BP1)]



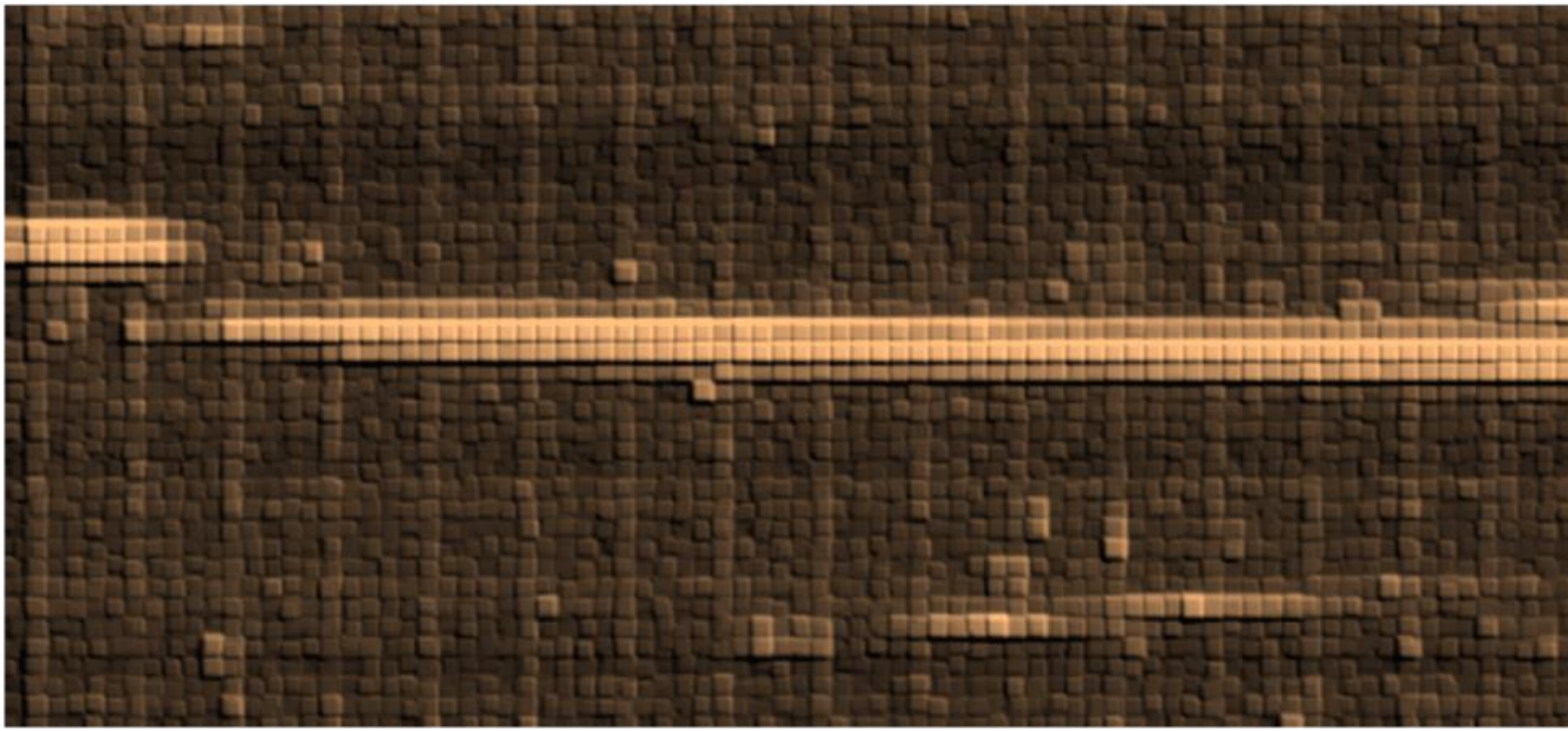

*© Inage Credit – Leica SP8 Confocal System at CRI / RaISE*

# Individual Tracks (13 vs 25 keV/μm)

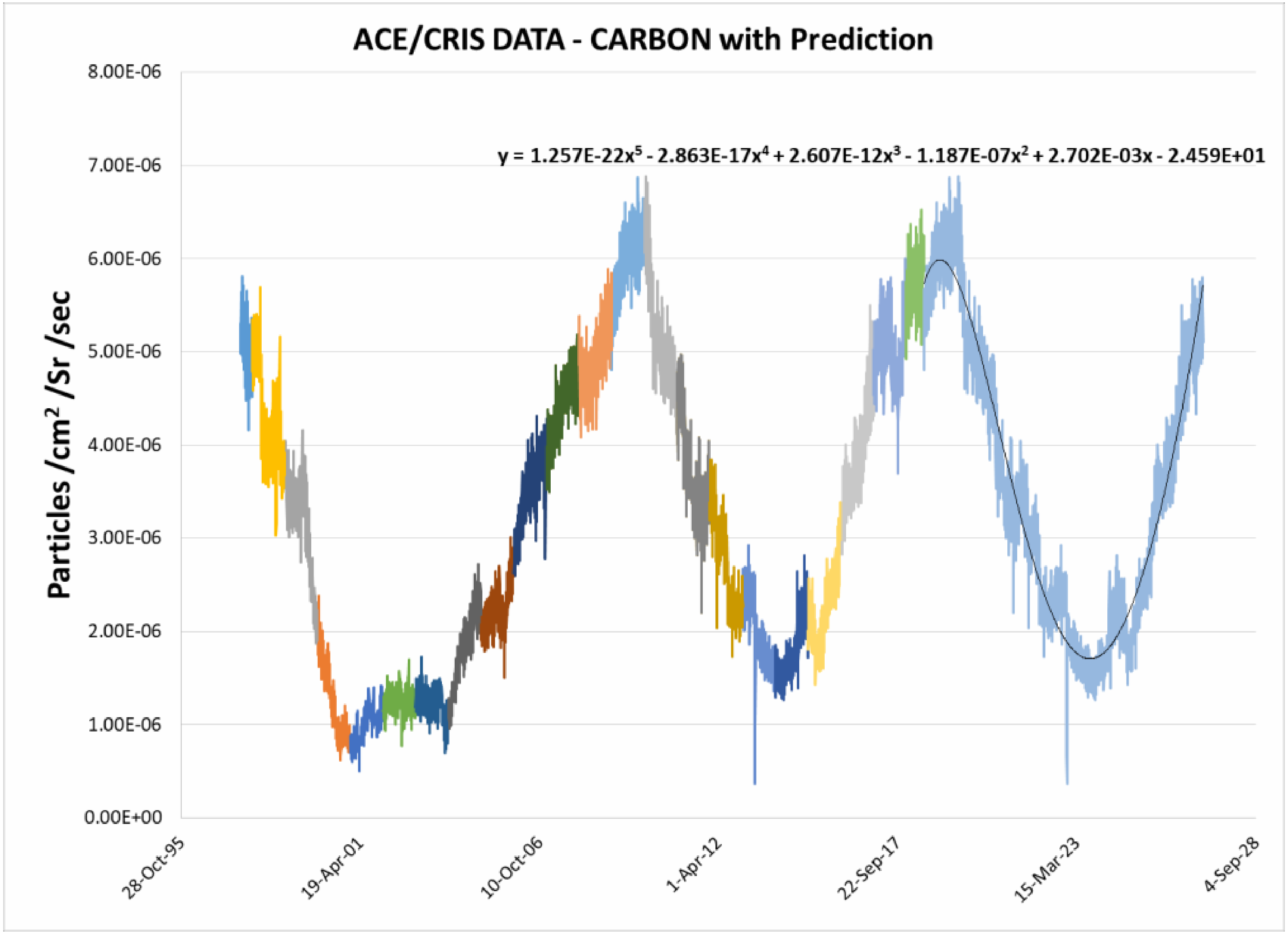


# Radiation Track Structure at Micron Level of Carbon Ions

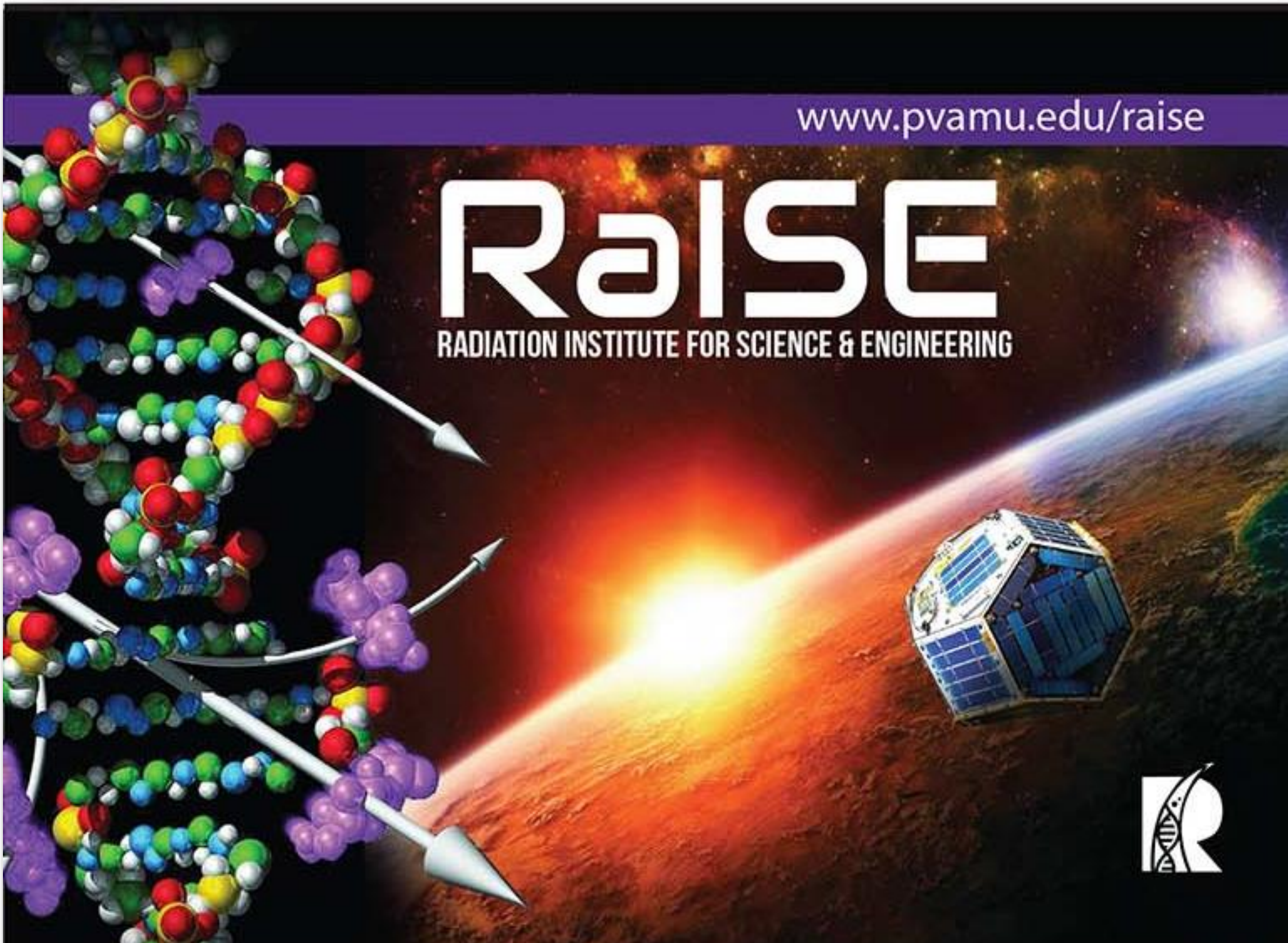




Radiation Track at 1.67 micron per pixel resolution for carbon ion with 300 MeV/n and LET 50 keV/μm (approximately 100x50 pixels are shown from about 3600x2700 pixel image)

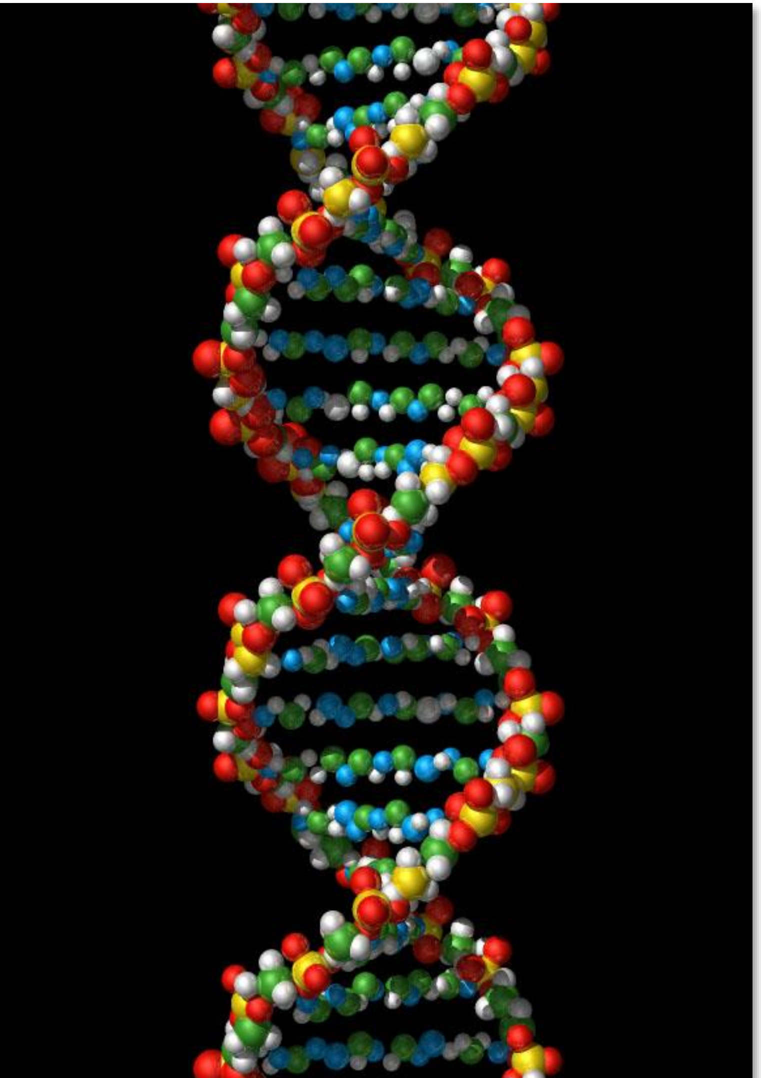


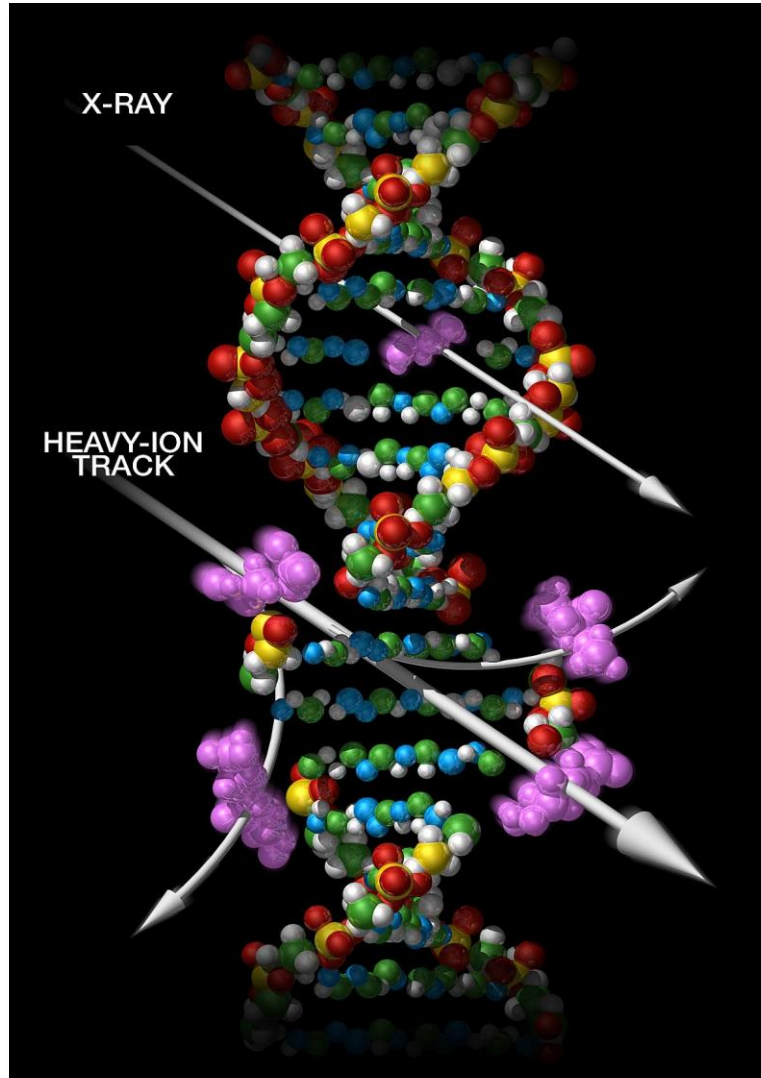

**ACE: Example of Carbon data (~ 25 years) with prediction for solar cycle # 25**

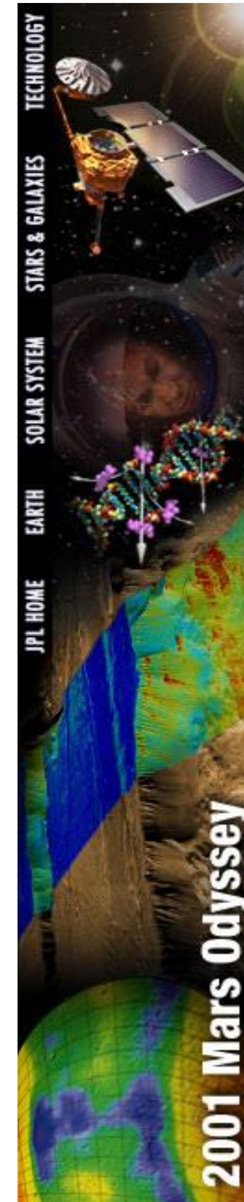

www.pvamu.edu/raise
RaISE
RADIATION INSTITUTE FOR SCIENCE & ENGINEERING

# Backup Charts

# © Cucinotta / Saganti: *National Geographic* January-2001

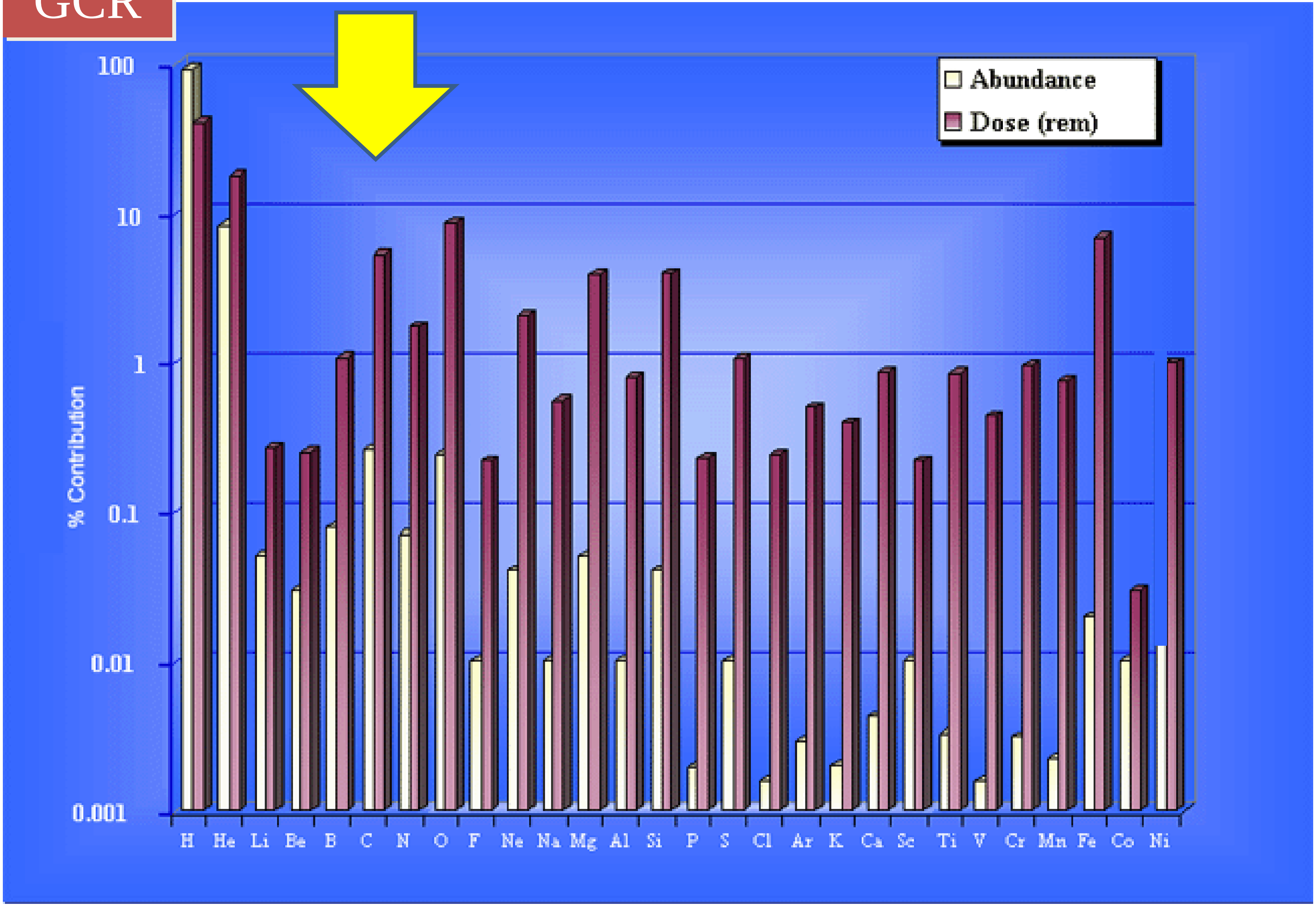





This illustration of DNA image (including radiation damage part) has been used and referenced in several books, numerous NASA websites, National Labs, major universities, and recruitment brochures of TAMU and others.

# GCR




Cucinotta / Saganti: 2001

http://srhp.jsc.nasa.gov/