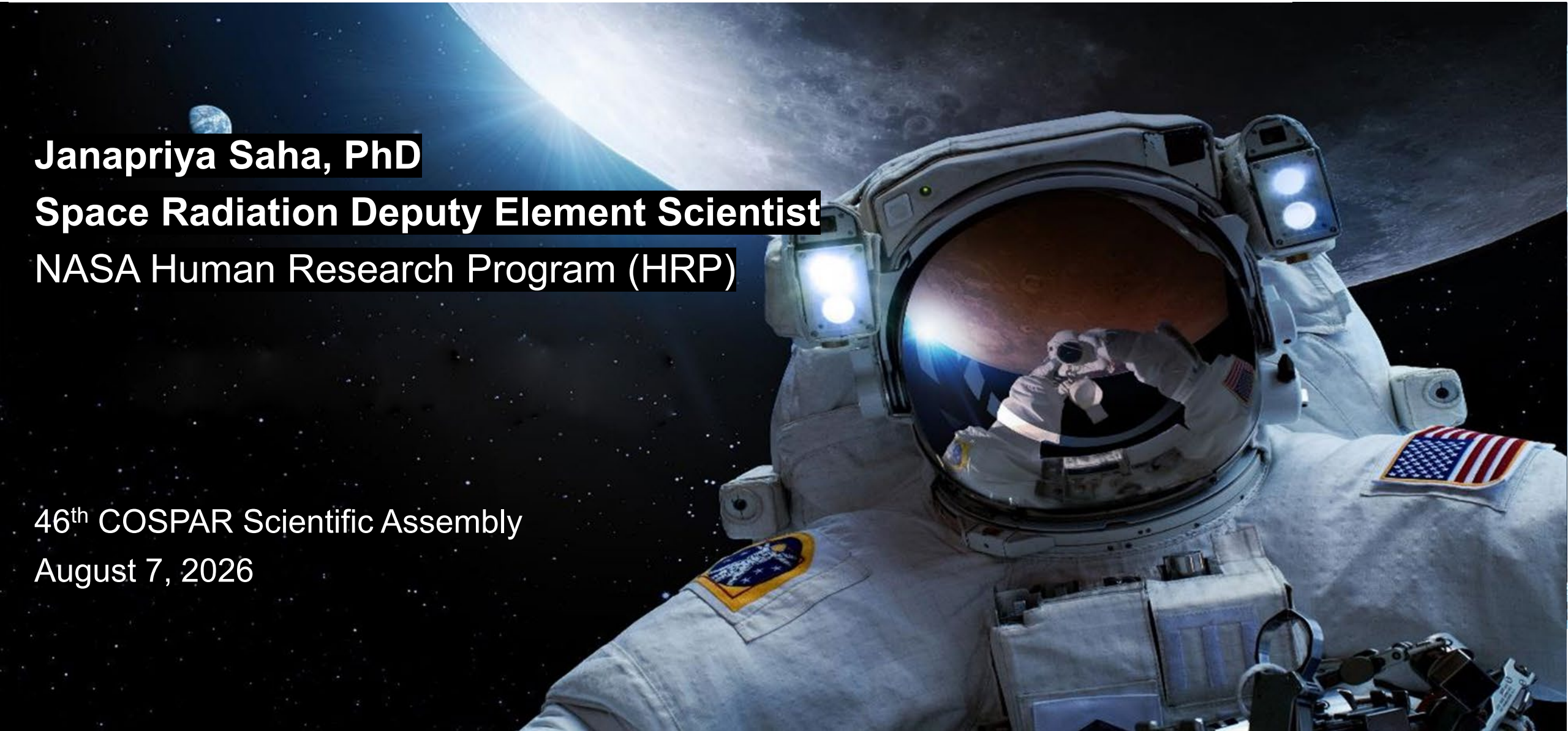
Overview of NASA Space Radiation Element Research and other Initiatives

National Aeronautics and Space Administration



Janapriya Saha, PhD
Space Radiation Deputy Element Scientist
NASA Human Research Program (HRP)

46th COSPAR Scientific Assembly
August 7, 2026

SRE Core Team



Janice Zawaski
SR Element Scientist



Janapriya "JP" Saha
SR Deputy Element Scientist



Marshleen Yadav
Cancer Discipline Lead



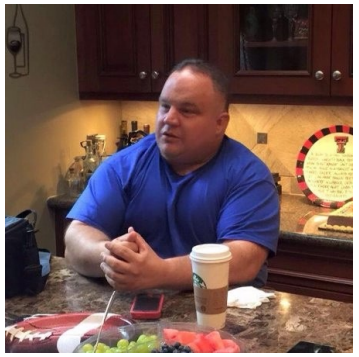
Diana Cruz-Topete
CVD Discipline Lead



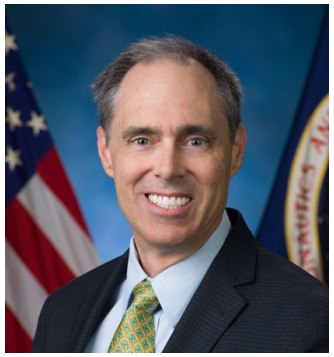
Greg Nelson
CNS Discipline Lead



Angela Kubik
Omics Specialist



Jason Weeks
SRE Manager



Aaron Allcorn
SR Deputy Element Manager

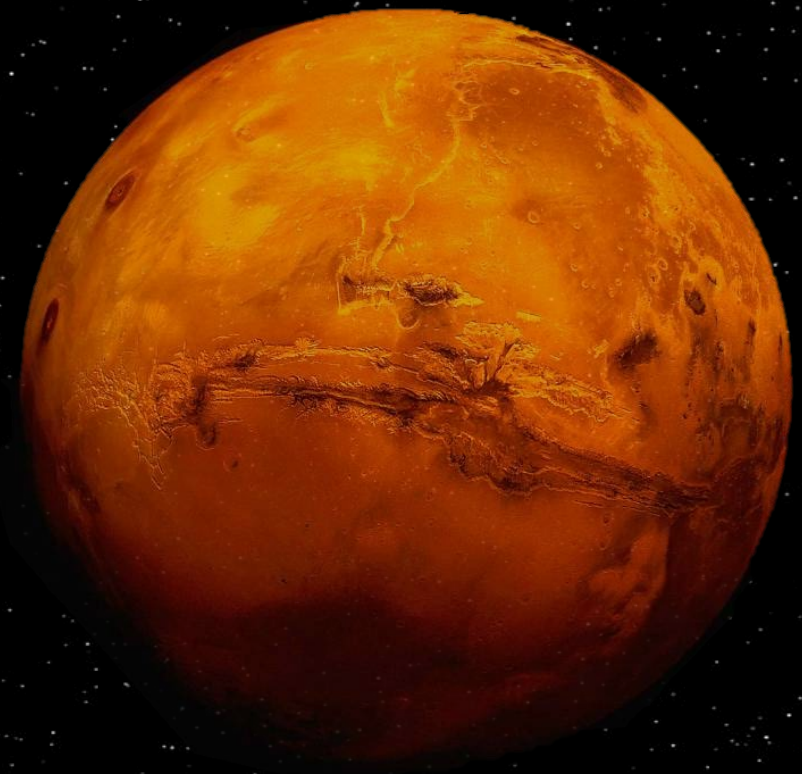


Jordan Rhone
Science Integrator

Jon McFather
Science Integrator

Human Research Program Mission:

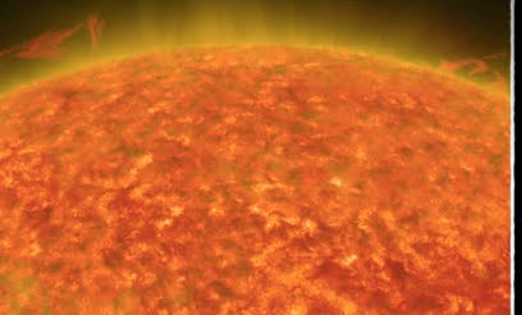
To enable space exploration beyond low Earth orbit by reducing the risks to human health & performance



1

Space Radiation

Invisible to the human eye, radiation increases cancer risk, damages the central nervous system, and can alter cognitive function, reduce motor function and prompt behavioral changes.





2

Isolation and Confinement

Sleep loss, circadian desynchronization, and work overload may lead to performance reductions, adverse health outcomes, and compromised mission objectives.

3

Distance from Earth

Planning and self-sufficiency are essential keys to a successful mission. Communication delays, the possibility of equipment failures and medical emergencies are some situations the astronauts must be capable of confronting.





4

Gravity (or lack thereof)

Astronauts encounter a variance of gravity during missions. On Mars, astronauts would need to live and work in three-eighths of Earth's gravitational pull for up to two years.

5

Hostile/Closed Environments

The ecosystem inside a vehicle plays a big role in everyday astronaut life. Important habitability factors include temperature, pressure, lighting, noise, and quantity of space. It's essential that astronauts stay healthy and happy in such an environment.



Space Radiation Element Research

- **Mission: Characterize and facilitate the management of the human health outcomes associated with space radiation exposure to protect astronaut health and wellbeing to enable human spaceflight**

  - **Three Funded Areas:**
    1. **Carcinogenesis**
  - **If radiation centric:**
    2. **Cardiovascular & Immune**
    3. **Central Nervous System**



Characterization ⟷ Mitigation		
Dose and Dose Rate Effects	Biomarkers	Countermeasure Identification
Radiation Quality	Individual Susceptibility	Countermeasure Validation
Cross-Species Translation	Combined Stressors	

Cancer Risk Approach Plan (New)

	Risk Characterization	Countermeasure (CM) Development, Evaluation, Validation, and Integration
HRR Knowledge Gap	**Cancer-103:** Determine the effects of **radiation quality** on cancer initiation, promotion, progression. **Cancer-104:** Determine the effects of radiation **dose and dose-rate** on cancer initiation, promotion, progression. Brookhaven National Laboratory 1 **NSCR update with Qnew development (2025)** **Cancer-202:** Evaluate the contribution of **genetic background/ diversity** on carcinogenesis risk. **Cancer-203:** Evaluate the **tissue-specific risks** of space radiation exposure on cancer outcomes. **Cancer-204:** Evaluate the **sex-specific risks** of space radiation exposure on cancer outcomes. Brookhaven National Laboratory 2 **NPR 8900 Baseline (PEL evaluation) (2025)** 3 **NPR 8900.1B Acceptance – Characterization Data (2030)**	**Cancer-403:** Identify and/or develop potential **biomarkers** to support health surveillance and countermeasure implementation. **Cancer-504:** Identify and validate **safe and effective countermeasures** to reduce radiation carcinogenesis. **Cancer-604: Operationalize validated pharmaceutical countermeasures and surveillance technologies** for spaceflight. Brookhaven National Laboratory 4, 8 **Clinical Practice Guideline (CPG) Recommendations (2030, 2038)** 5 **Countermeasure Identification (2036)** 6 **8900 Acceptance - Mitigation Data (2038)** 7 **Integrated CM Toolkit (2038)** 9 **Fitness for Duty Standard Recommendations (2040)**

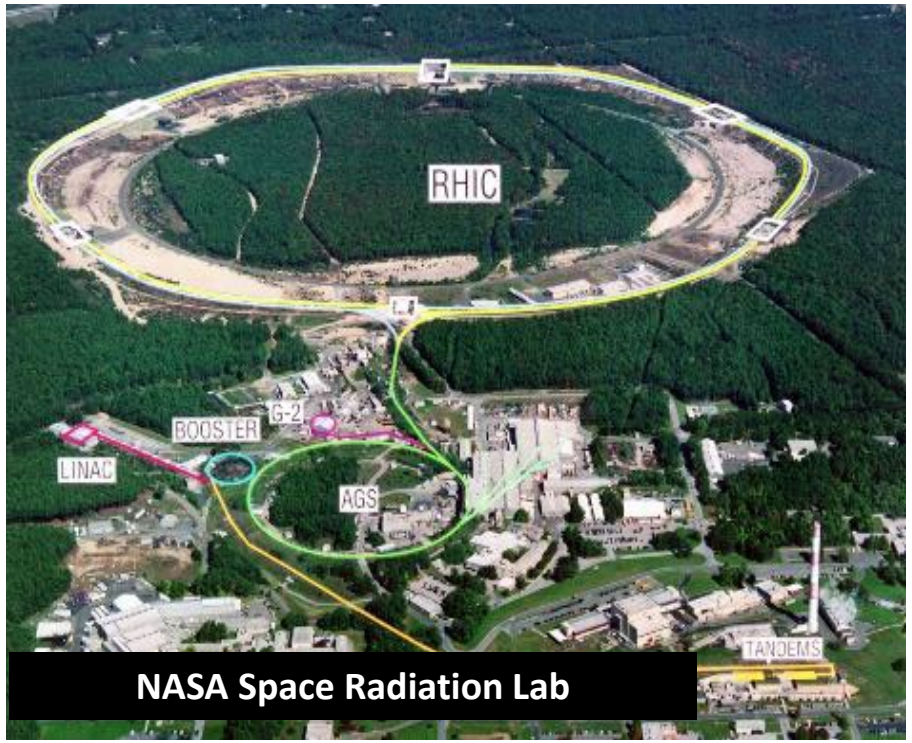
Legend: M2M Deliverable; Lunar Deliverable; ISS; Brookhaven National Laboratory; Artemis

Timeline

1, 2 — 2025 — 3, 4 — 2030 — 5 — 6, 7, 8 — 2038 — 9 — 2040

Risk Maps to ESDMD Gap ID # 0308

Ground Analog – NASA Space Radiation Laboratory



NASA Space Radiation Lab

https://www.nasa.gov/analogs/nsrl/about

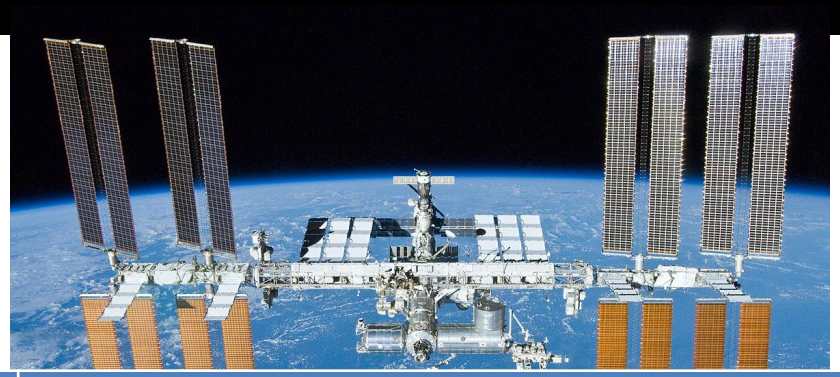
https://www.bnl.gov/nsrl/

Personnel:
NSRL liaison physicist, Dr. Mike Sivertz
Biology support scientist, Dr. Peter Guida (guida@bnl.gov)
NSRL Management, Lisa Simonsen Ph.D.

Capabilities:
- Acute or fractionated exposures “chronic”
- Single ions
- Multiple ions
  - Simplified GCR sim [6 beams 5 ions: H (2 energies), Si, He, O, & Fe]
  - GCR sim [33 beams, 7 ions: H (14 energies), He (14 energies), C,O, Si, Ti, & Fe]

Budgeting:
- Beam time is covered if funded by the Space Radiation Element
- Animal Housing costs (acclimation and during irradiation)
- Personnel travel/housing/per diem costs (onsite personnel is need during experiment)

What's out there? The Space Radiation Environment





Exposure Type	ISS (51.6^{o} inclination)	Beyond Low Earth Orbit (LEO)
Galactic Cosmic Rays (GCR)	• **Limited to polar regions** • Fractionated low dose-rate • ~ 87% protons, 12% Helium, 1% High charge and Energy (HZE)	• **Continuous** • Chronic low dose-rate • ~ 87% protons, 12% Helium, 1% HZE
Trapped Radiation	• **South Atlantic Anomaly (SAA)** • Fractionated low dose-rate • Protons	• **Transit through Van Allen Belts** • Quasi-acute • Protons
Solar Particle Events (SPEs)	• **Limited to polar regions** • Fractionated low dose-rate • Protons	• **Full Event** • Quasi-acute • Protons
Neutrons, Secondary Radiation	• Shielding affects Secondary Radiation • Chronic low dose-rate	• Shielding affects Secondary Radiation • **Planetary (albedo)** • Chronic low dose-rate

The Space Radiation Protection Challenge

Traditional terrestrial protection strategies fall short in space:

- Time
  - At some point you will always reach a limit
- ✗ Distance
  - There is no point source to move away from
- ✗ Shielding
  - Energetic particles are penetrating
  - Secondary particles

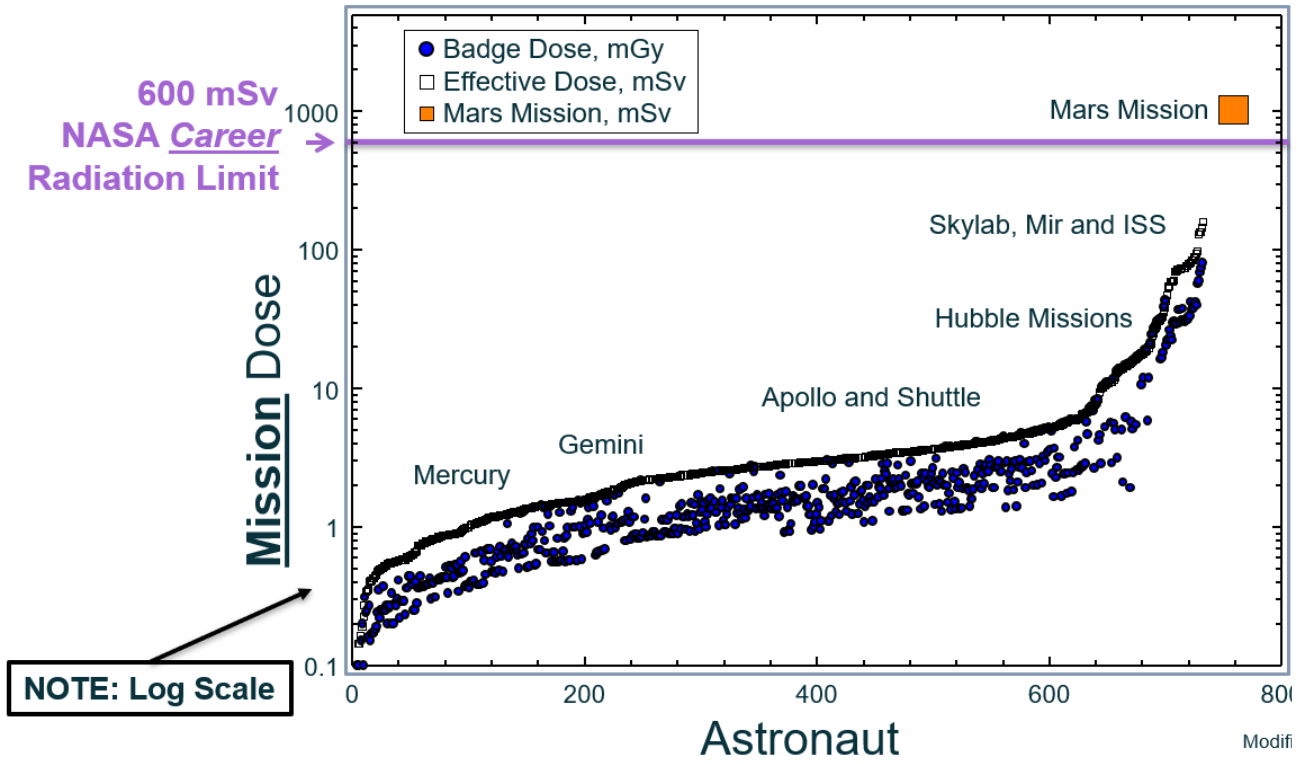


NASA is exploring other protection strategies:

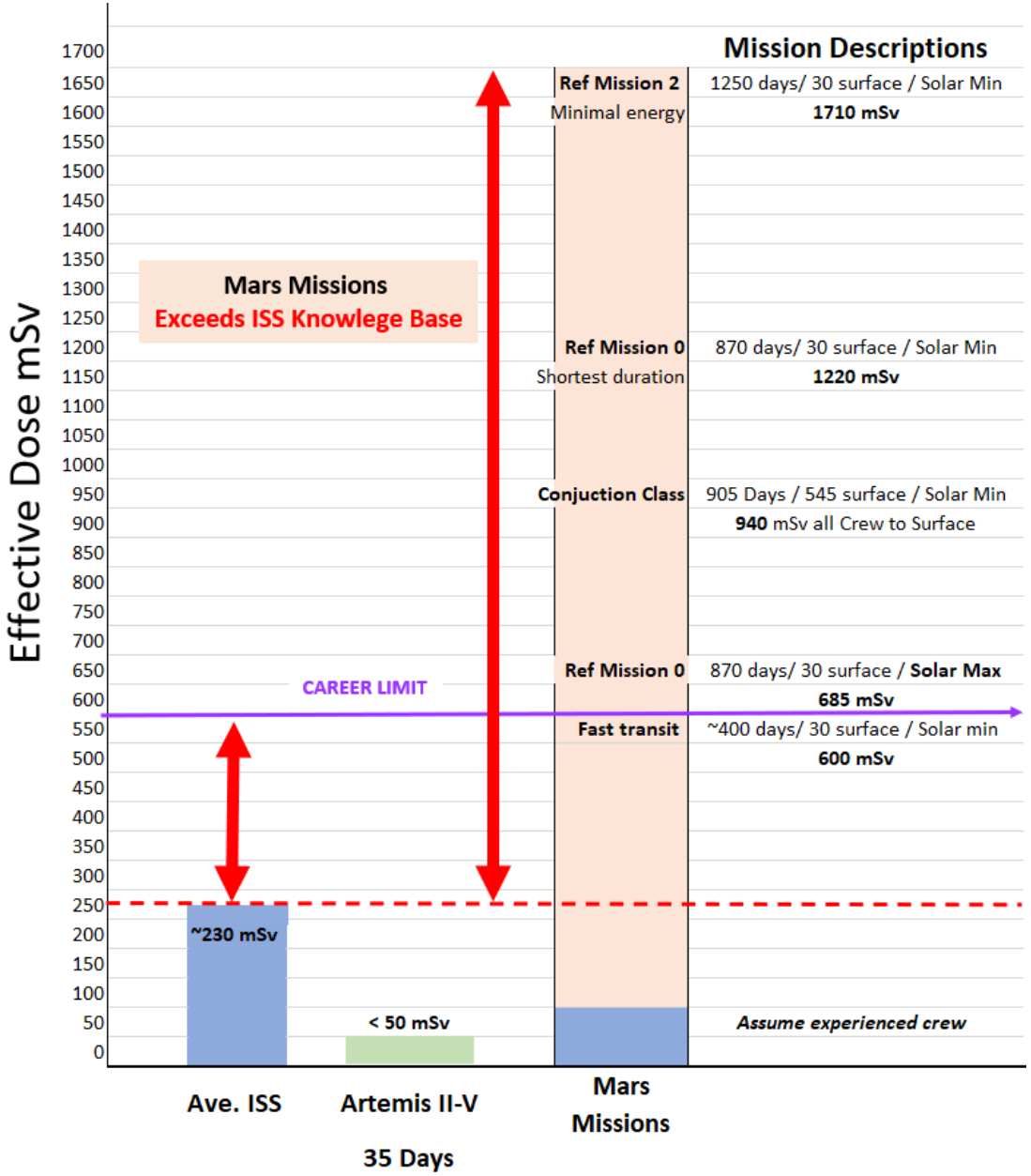
- Individualized risk characterization
- Health surveillance including early disease detection
- Compound-based countermeasures

- **Each crew member is badged**
- **Active radiation area monitoring**

Historical and Future NASA Crew Mission Doses

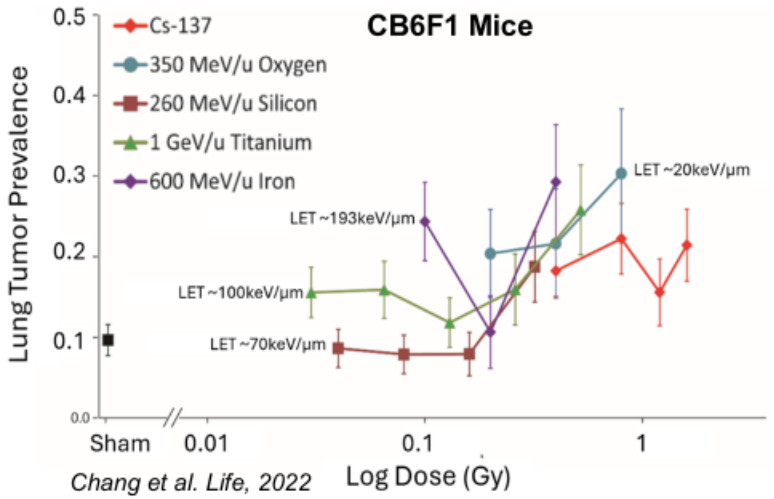


Mission	Exposure mSv
Earth Rad Worker / lifetime	20
ISS Experience	230
Artemis II-V	50
Long Duration Increments /Cislunar	500
Mars Demo Mission	1650



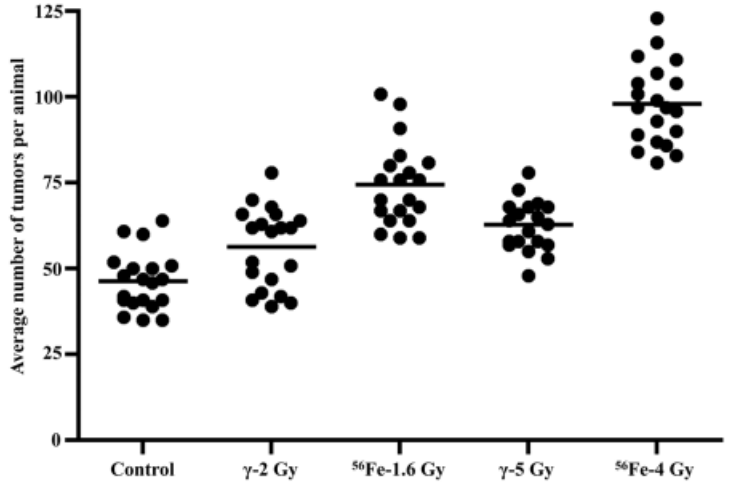
Tumor Prevalence after Space-type IR Exposure

Lung tumor prevalence as a function of dose and HZE ion



Chang et al. Life, 2022

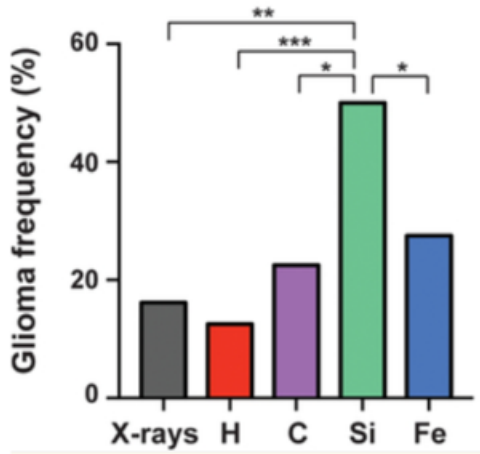
Heavy ions-induced intestinal tumor in APC$^{Min/+}$ mice



Dutta et al 2013

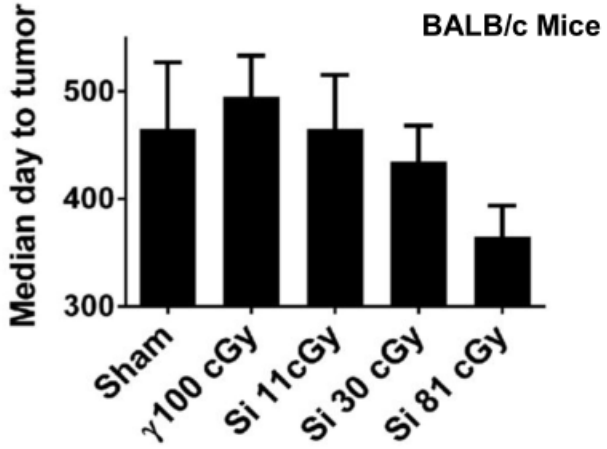
Clustered DSBs cooperate with preexisting tumor suppressor losses to generate high-grade gliomas.

NesCre p53+/f:PTEN+/f mice survival post 0.5 Gy IR



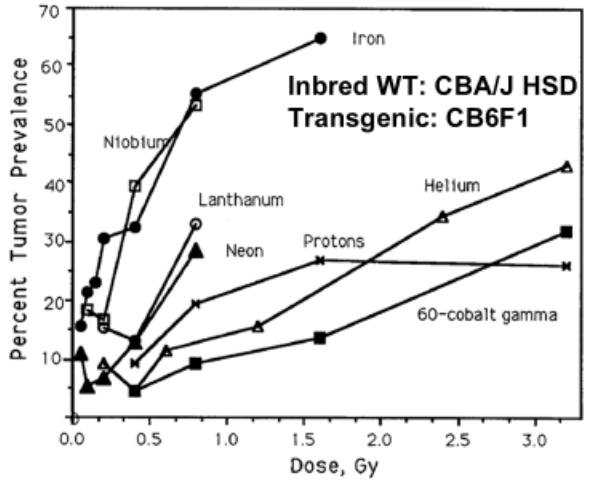
Todorova et al 2019

Mammary tumors in Trp53-null



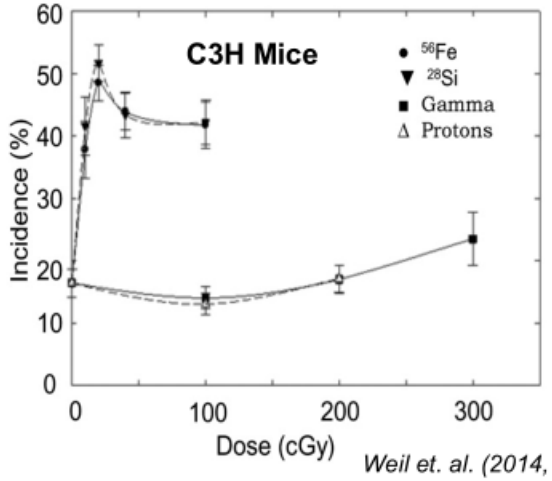
Illa-Bochaca et al 2014

Harderian gland tumor prevalence as a function of dose



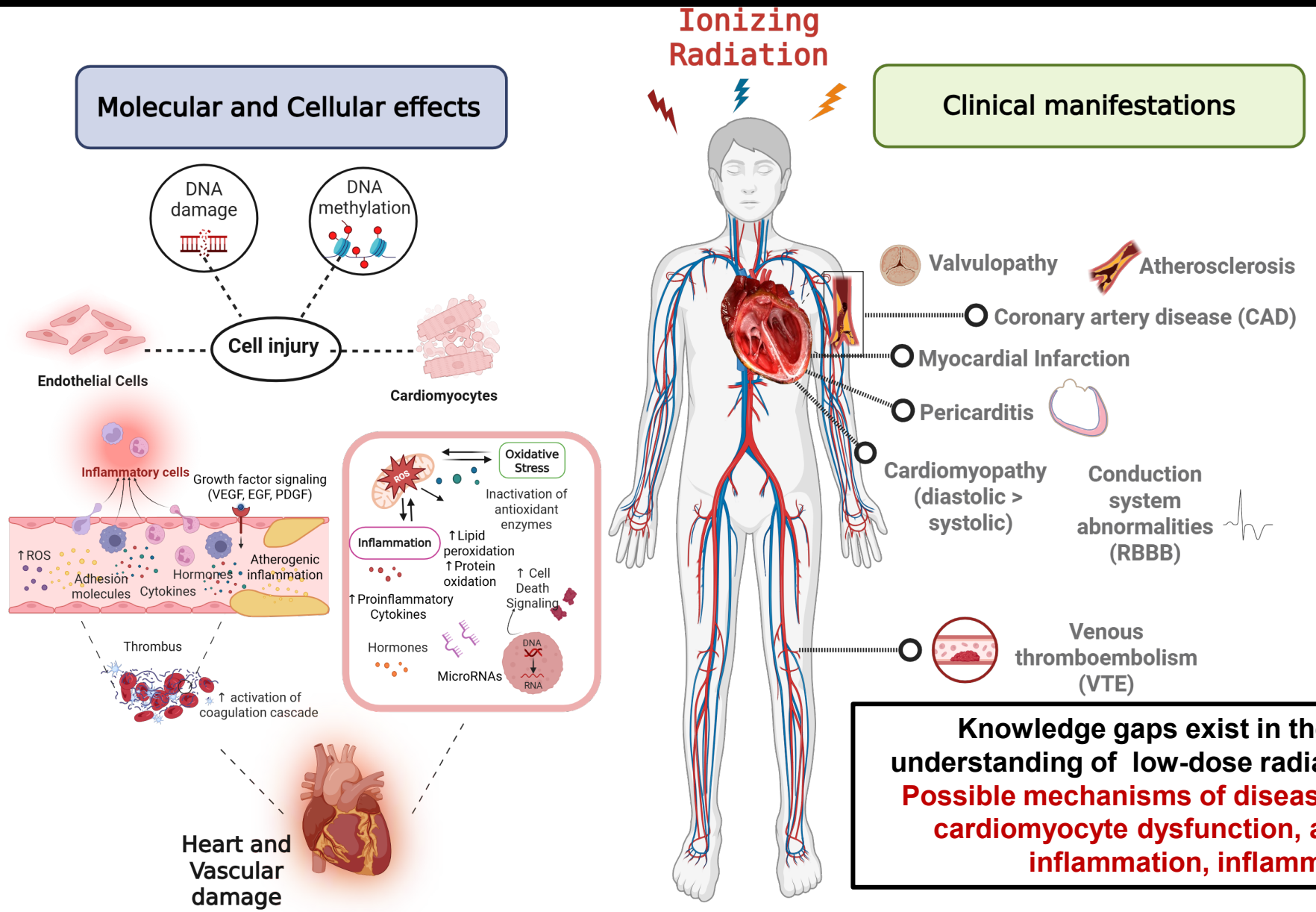
Alpen et al 1993; Change et al 2016; Kennedy et al 2008, 2011

Induction of HCC as a function of dose of HZE ions and 1972SPE protons.



Weil et. al. (2014, PLOS One)

Putative Mechanisms of Radiation-induced CVD

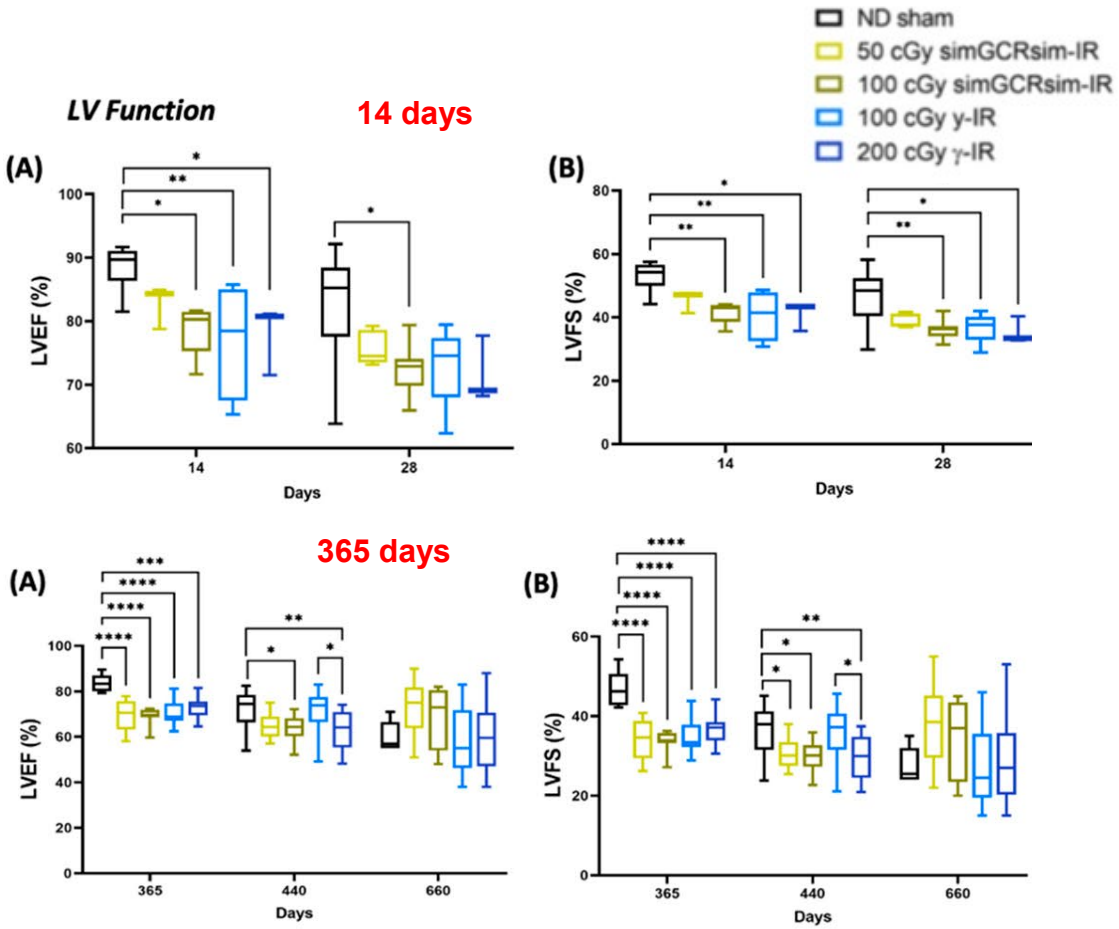


Knowledge gaps exist in the mechanistic understanding of low-dose radiation-induced CVD.
Possible mechanisms of disease: endothelial and cardiomyocyte dysfunction, atherosclerosis, inflammation, inflammasomes

Cruz-Topete D, and Nelson G.A. et al. Unpublished 2025

Cardiovascular Structural and Functional Changes

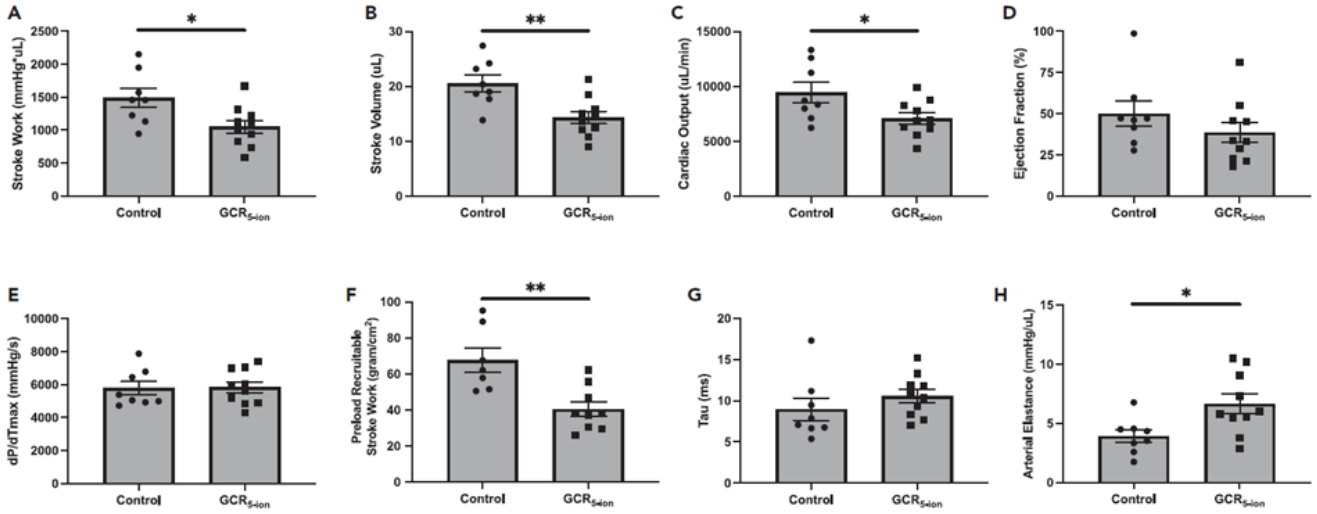
Acute and late degenerative effects in Left Ventricular Function



By 14 days and 365 days post IR, global LV systolic function (echocardiography), as indicated via LVEF and LVFS, decreased in IR treatment groups in WT mice (C57BL/6J)

Brojakowska A et al. (2023) Int. J. Mol. Sciences

Pressure-volume loop (PVL) analyses reveal decreased systolic function and increased arterial elastance one year after 150 cGy GCR 5-ion beam



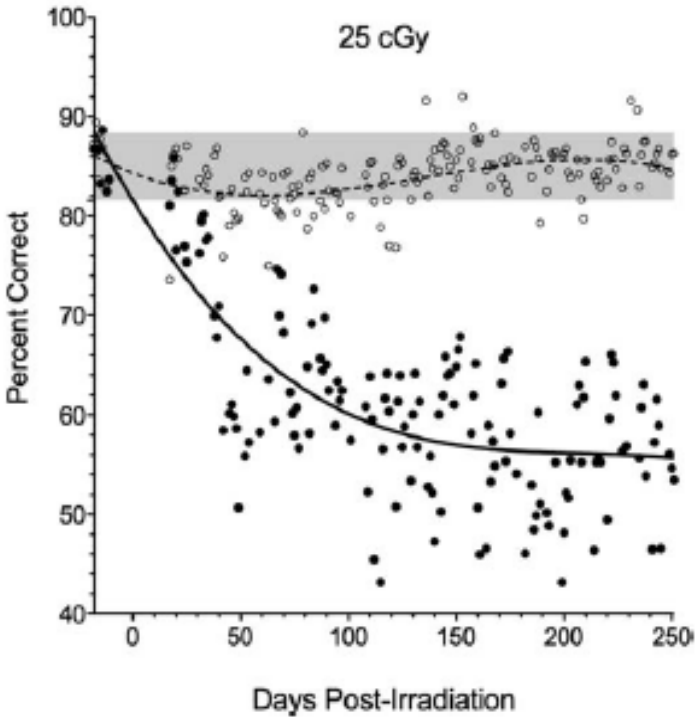
Significant diminishment in load-dependent measures of cardiac function, including stroke work (SW), stroke volume (SV), and Cardiac Output (CO) 365 days post GCR

Bishawi M et al. (2022) iScience

Behavioral Responses after Space-type IR Exposure

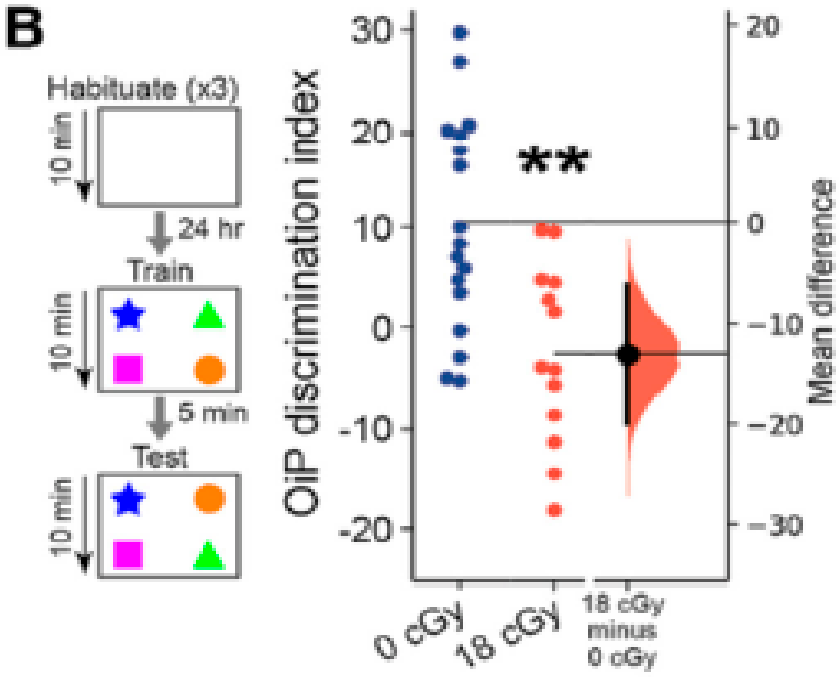
Persistent behavioral changes in cognitive, emotional and sensorimotor domains are observed in rats and mice after single or multi-ion exposures and neutrons.

In a high-fidelity human analog paradigm, psychomotor vigilance is impaired in rats after proton irradiation



Davis et al. (2014) Radiat. Res. 181, 258–271

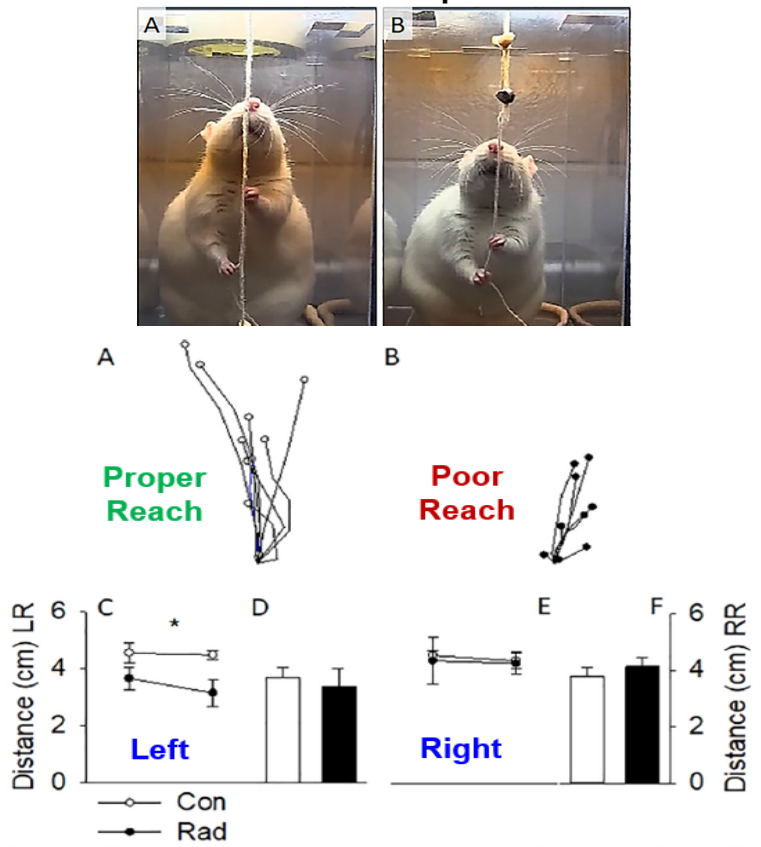
Object in Place Test Reveals Impairments in Spatial Memory after 18 cGy Neutron Exposure



Spatial memory behavior is perturbed by acute neutron irradiation in Object in Place (OiP) test to differentiate objects relocated to alternative locations.

Klein et al. (2021) Int. J. Mol. Sci. 22:9020

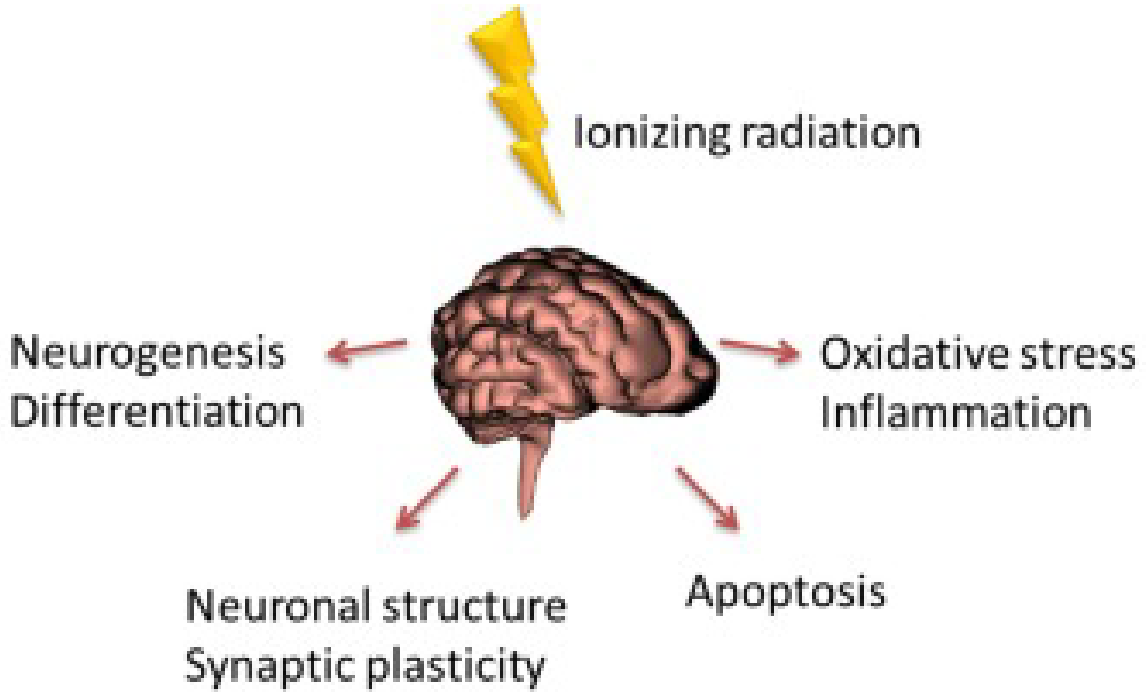
Movement topography is altered in the fine motor skill "string-pulling" test in rats after Si exposure.



Blackwell et al. (2020) Behav. Brain Res. 400, 113010

Summary of Changes to the Central Nervous System

- **Changes in neurochemicals, synaptic and neuroinflammatory proteins**
- **Increased activation of microglia (signaling neuroinflammation)**
- **Deficits in neurocognitive performance for several mouse and rat behavioral paradigms**
- **High-LET nuclei at low doses (<10 cGy) significantly reduced production of new neurons in brain** (data not shown)
- **Reduction in neuron arborization and synapse number (dendritic spines)**
  - Persistent reductions for > 1 year after doses of high Linear Energy Transfer (LET) nuclei below 5 cGy (data not shown)



Performance deficits following exposure to high-LET nuclei depends on

- Physical particle characteristics, strain, sex, age at exposure, evaluation time after exposure and measure used
- Male mice appear to be more radiosensitive than female mice

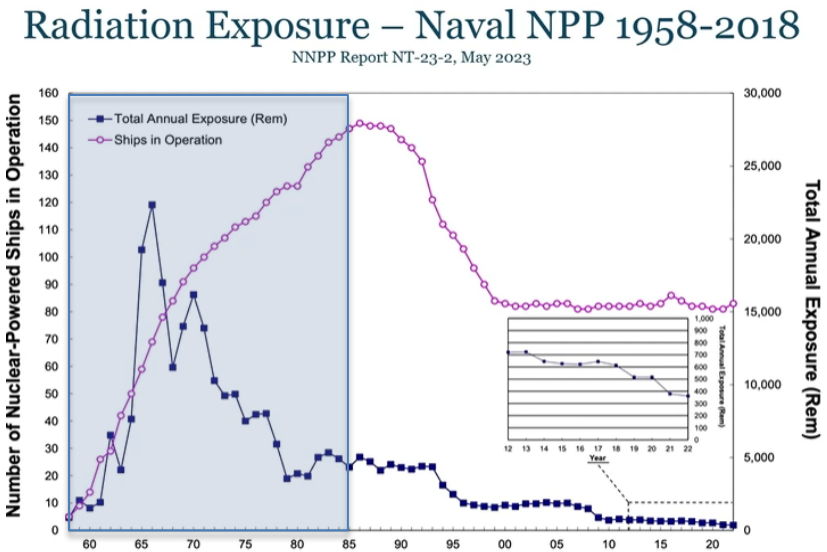
The U.S. Million Person Study or Low-Dose Rate Health Effects:
Innovations in Evaluating Cognition and multiple Stressors

Objective:

- **Million Person Study (MPS) Navy Submariner Cohort – Terrestrial Space Analogue**
  - **Radiation exposure**
  - **Isolation and confinement**
- **Could inform risk estimates but also post-mission surveillance**
- **Can be extended to other radiation associated risks**

OBSERVATIONS:

- **Submariners from1954-1985 and followed through 2021**
- **Mean time served 3.2 years, 44.5% of individuals served 3 years or more**
- **Mean follow-up time 43.1 years,**
  - **45.4% of individuals have for more than 40 years of follow-up**

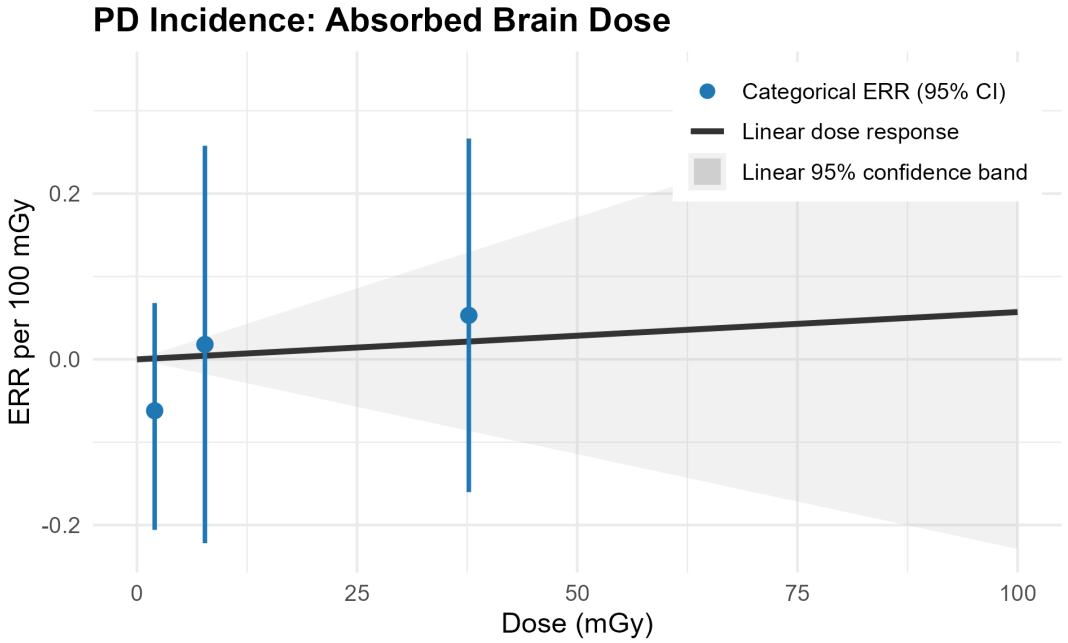


Years 1960-2022

Navy (NDC) Career PHOTON Dose (mSv)

Dose (mSv)	Frequency	Percent
0 - < 0.2	3,975	3.53
0.2 - < 1	40,067	35.58
1 - < 2	19,102	16.96
2 - < 5	18,789	16.68
5 - < 10	12,163	10.80
10 - < 20	9,978	8.86
20 - < 50	6,710	5.96
50 - < 100	1,581	1.40
100 - < 250	248	0.22
250 - < 1,000	9	0.01

Preliminary data = 0.17 ERR at 100mGy



Adjusted for YOB (ns, df = 4), Rank (Officer/Enlisted), Tobacco use (Y/N), Nuclear power training (Y/N)

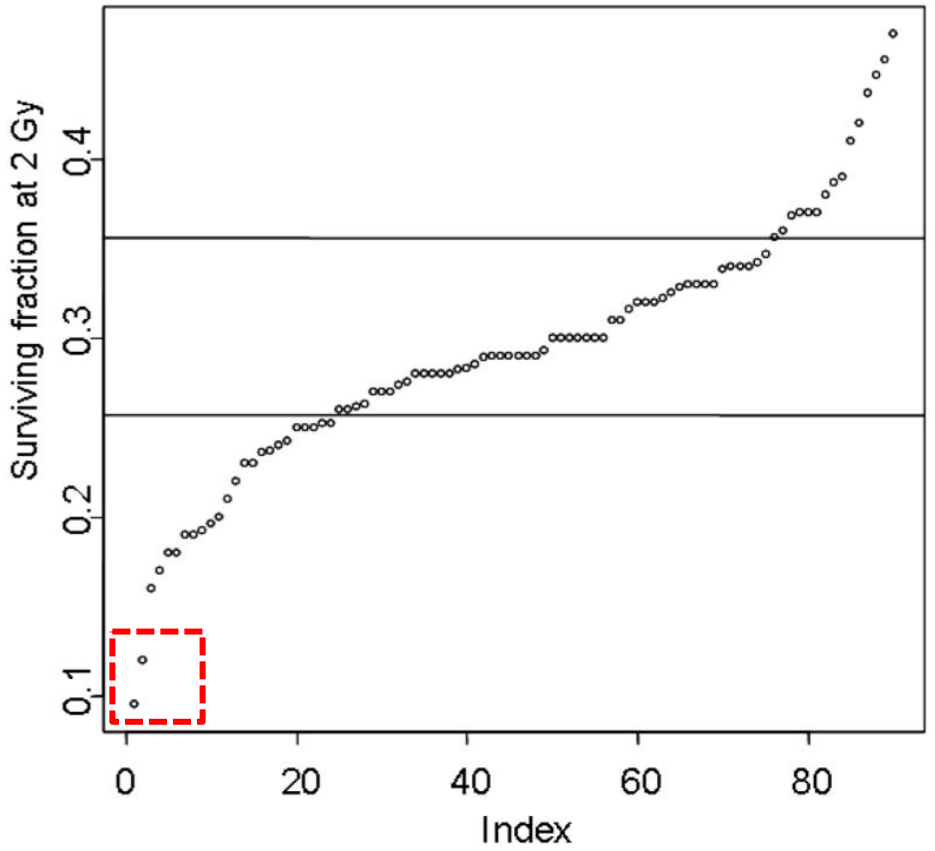
Evaluation of the Cellular & Molecular Responses of Lung and Liver Cells Derived From iPSCs With Varying Intrinsic Radiosensitivity to Space Radiation

PI: Anthony “Tony” Davis / UTSW

Objective: PHSFs will be utilized to generate immortalized PHSFs, induced pluripotent stem cells (iPSCs), and iPSC-derived hepatocytes and lung epithelial cells, whose intrinsic radiosensitivity is the same as that of the original PHSF from which it was derived.
Irradiation: Gamma, simplified GCRsim
Outcomes:

- Clonogenic survival
- DNA repair
- DDR signaling
- Genome stability
- Mutation frequency and cellular and oncogenic transformation assays
- Transcriptome
- Whole genome sequencing, DNA methylation, and RNAseq analysis

The ability to identify individuals at greatest risk (or lowest risk) for carcinogenesis induced by low and high LET irradiations would be invaluable. Also, it may inform tissue sensitivity.

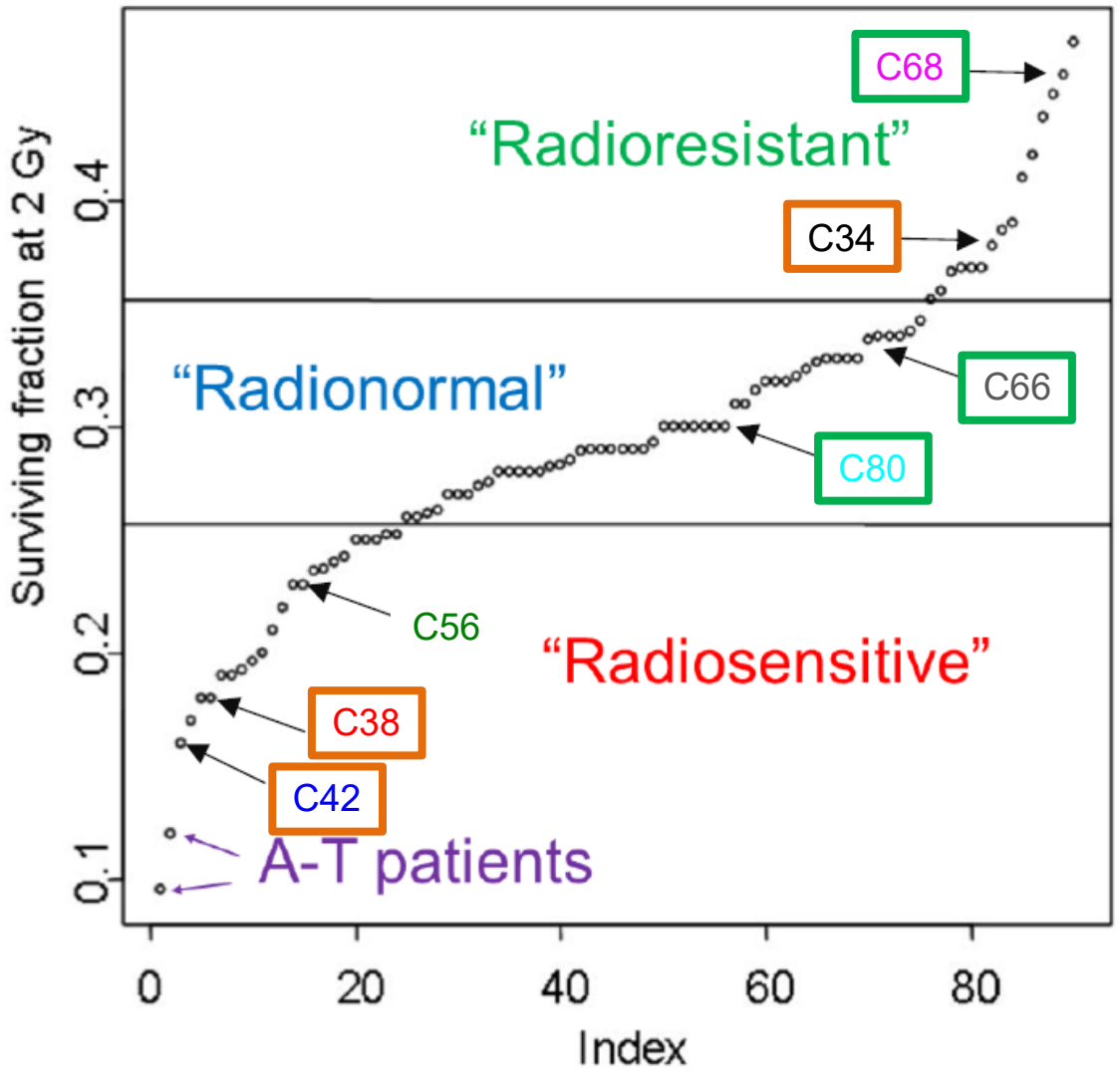


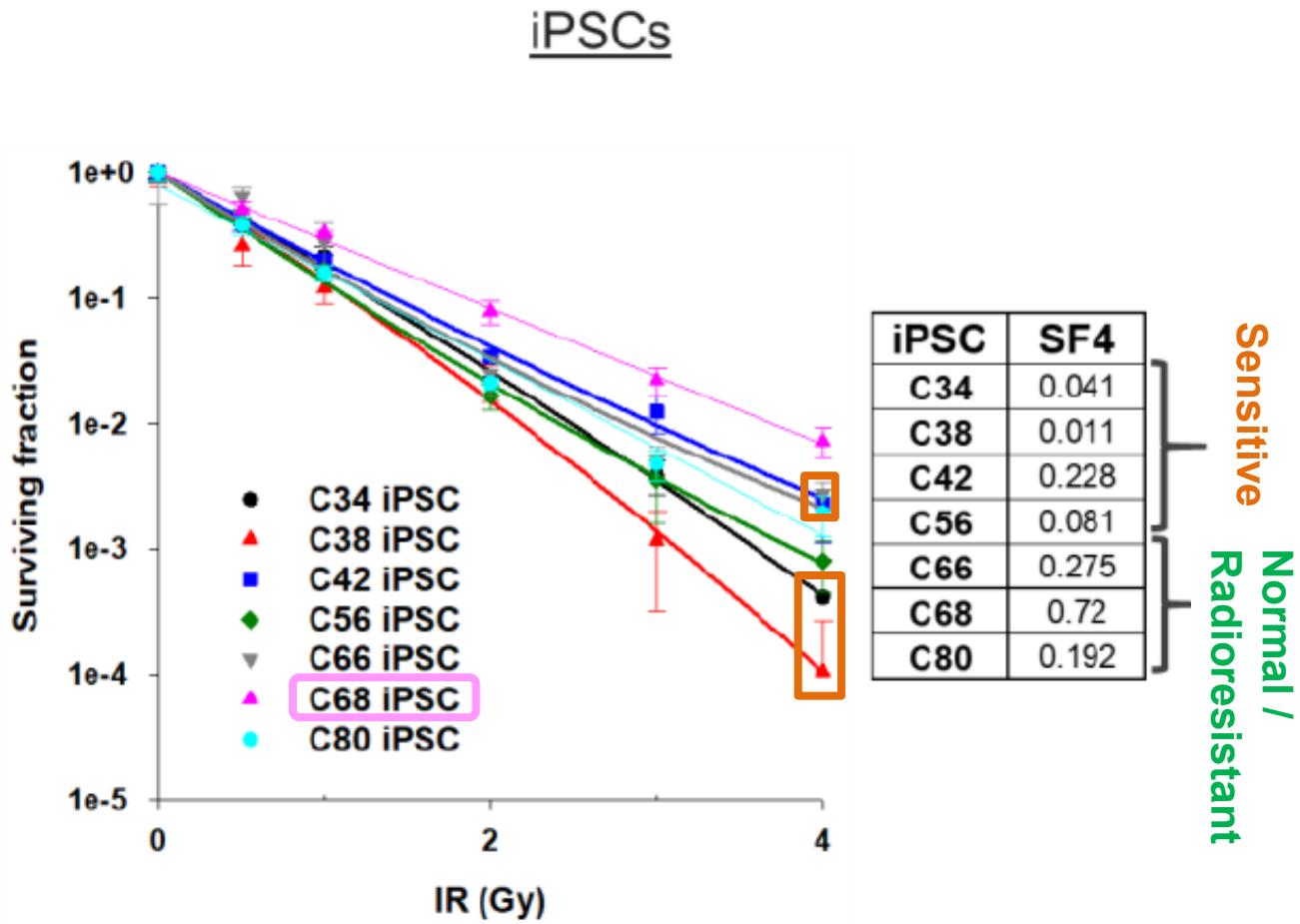
Radiosensitivity of 90 skin fibroblast cell lines as measured by SF2. Horizontal lines demarcate group-based radiosensitivity: radiosensitive, normal, and radioresistant. Dashed box: Ataxia telangiectasis Cell Line

Health Phys. 2012 Nov; 103(5): 596–606.

Evaluation of the Cellular & Molecular Responses of Lung and Liver Cells Derived From iPSCs With Varying Intrinsic Radiosensitivity to Space Radiation

PI: Anthony “Tony” Davis / UTSW

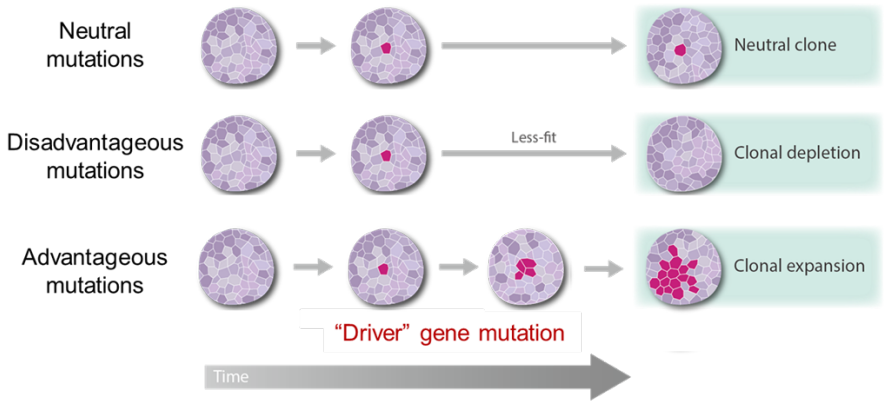




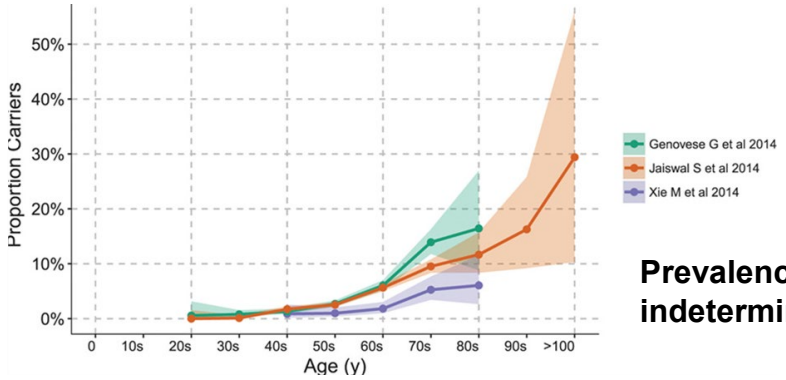
iPSC	SF4
C34	0.041
C38	0.011
C42	0.228
C56	0.081
C66	0.275
C68	0.72
C80	0.192

Clonogenic survival assays were performed to compare the radiation sensitivities of the iPSCs. Cells were irradiated at the indicated doses and plated for analysis of survival and colony-forming ability. The inset shows the survival fraction at 4 Gy (SF4) for each iPSC.

Clonal Hematopoiesis of Indeterminate Potential (CHIP)



- CH is a condition when a hematopoietic stem cell (HSC) acquires a mutation that gives it a competitive growth advantage over other stem cells, allowing it to clonally expand.
- The presence of mutations in known CH "driver" genes, with **VAF ≥2%**, is termed CH of indeterminate potential (CHIP).
- Common driver genes are DNMT3A, TET2, ASXL1, JAK2, TP53, PPM1D, etc.

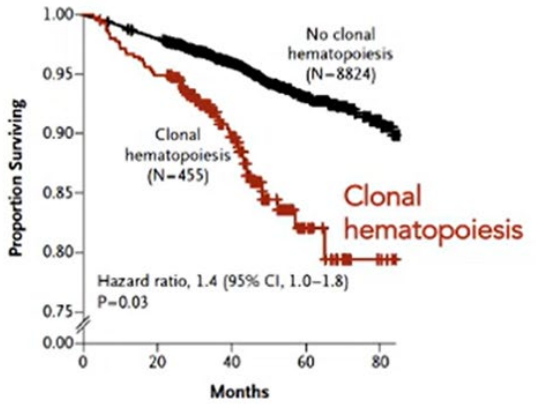


Prevalence of clonal hematopoiesis of indeterminate potential by age.

Circ Genom Precis Med. 2018 Jul;11(7):e001926. doi:10.1161/CIRCGEN.118.001926.

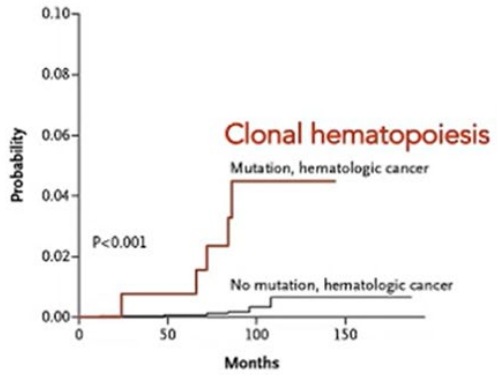
Mortality

Genovese et al. *NEJM* 2014



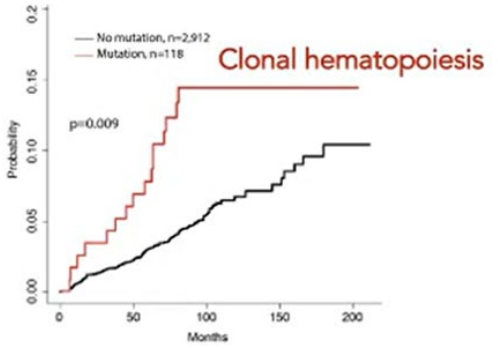
Hematologic cancer

Jaiswal et al. *NEJM* 2014



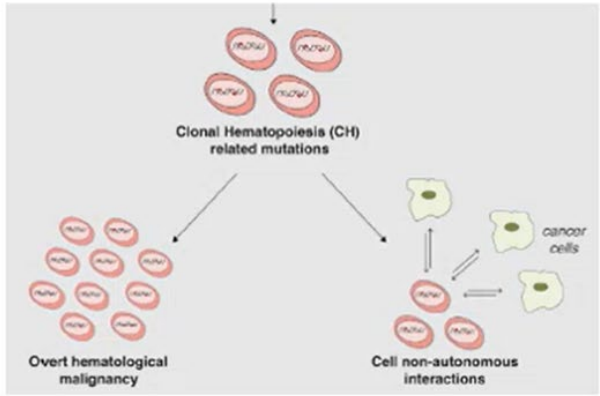
Coronary heart disease

Jaiswal et al. *NEJM* 2014



Solid cancers

Coombs et al. *Cell Stem Cell* 2017



Genovese et al. NEJM 2014

CHIP in Astronauts

PI: Dr. David Goukassian

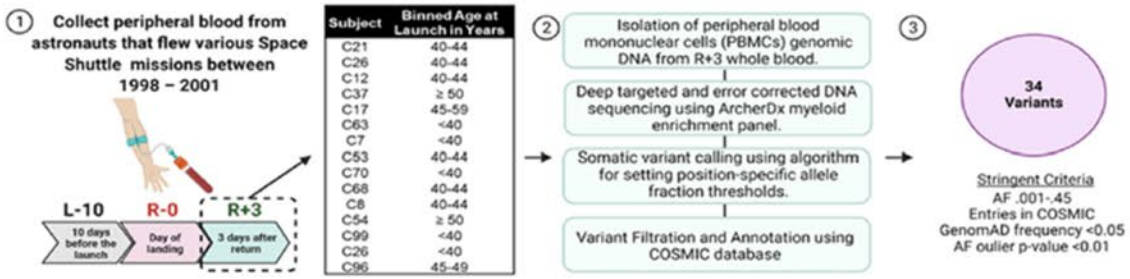
communications biology

ARTICLE

https://doi.org/10.1038/s42003-022-03777-z OPEN

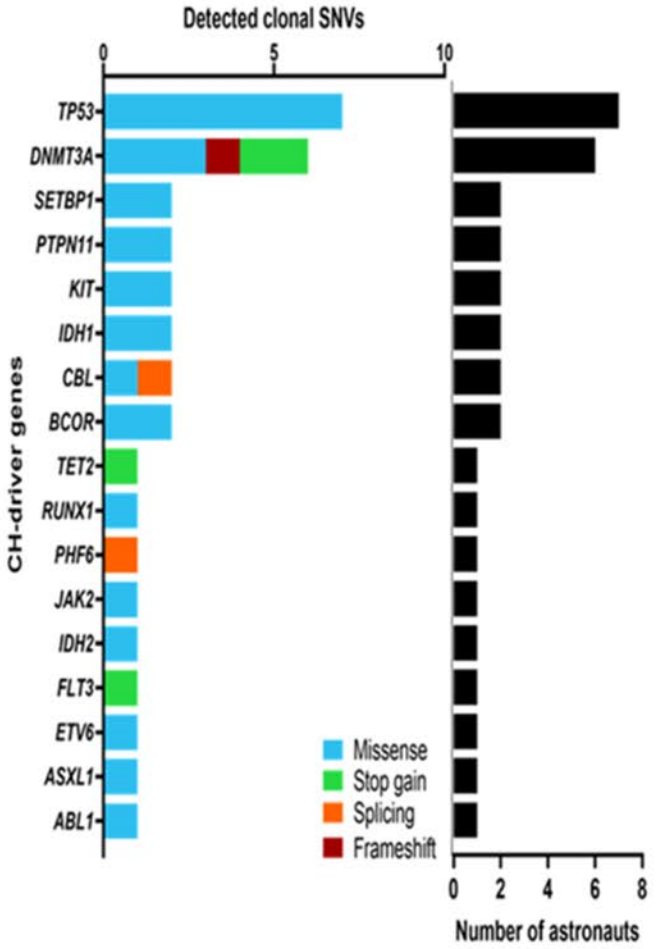
Retrospective analysis of somatic mutations and clonal hematopoiesis in astronauts

Agnieszka Brojakowska[1,5], Anupreet Kour[2,5], Mark Charles Thel[2], Eunbee Park[2], Malik Bisserier[1], Venkata Naga Srikanth Garikipati[3], Lahouaria Hadri[1], Paul J. Mills[4], Kenneth Walsh[2] & David A. Goukassian[1]✉

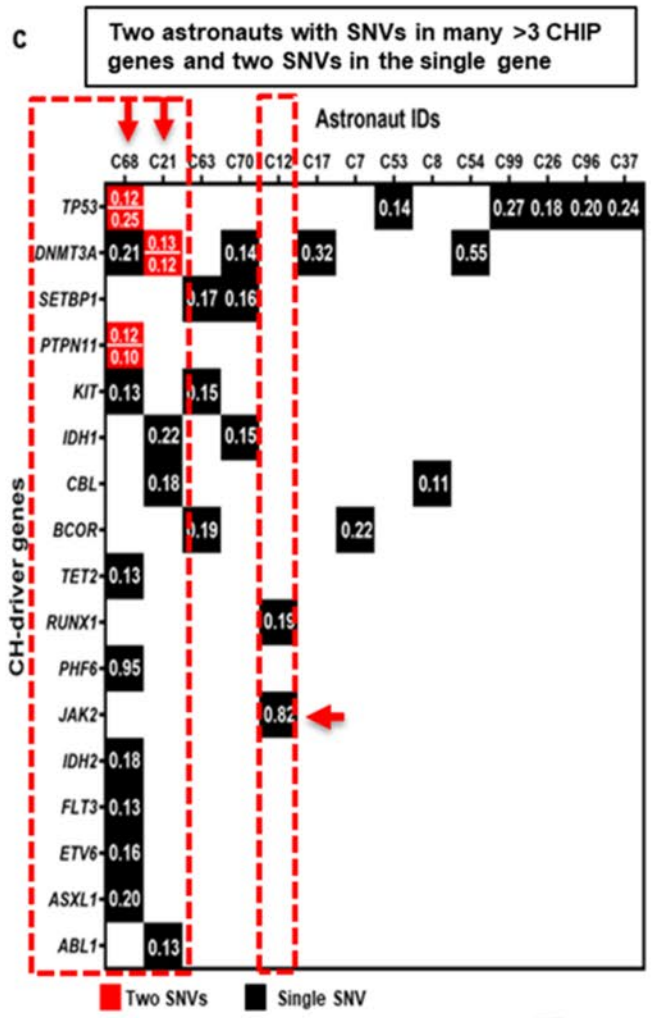


- Identified 34 nonsynonymous SNVs in 17 known CH-driver genes, of which TP53 and DNMT3A were the most frequent.
- 5/14 astronauts harbored mutations in at least two CH-driver genes, and subject C68 had variants in the four mutated genes.
- Clone size did not achieve the technical threshold of CHIP.
- The DDR gene TP53 was the most frequently mutated in this astronaut cohort (median age 44 years, range 37–67).

Mutational profile of 17 known mutated CHIP-driver genes and number of astronauts with mutations in each gene



Mutation plot for each astronaut

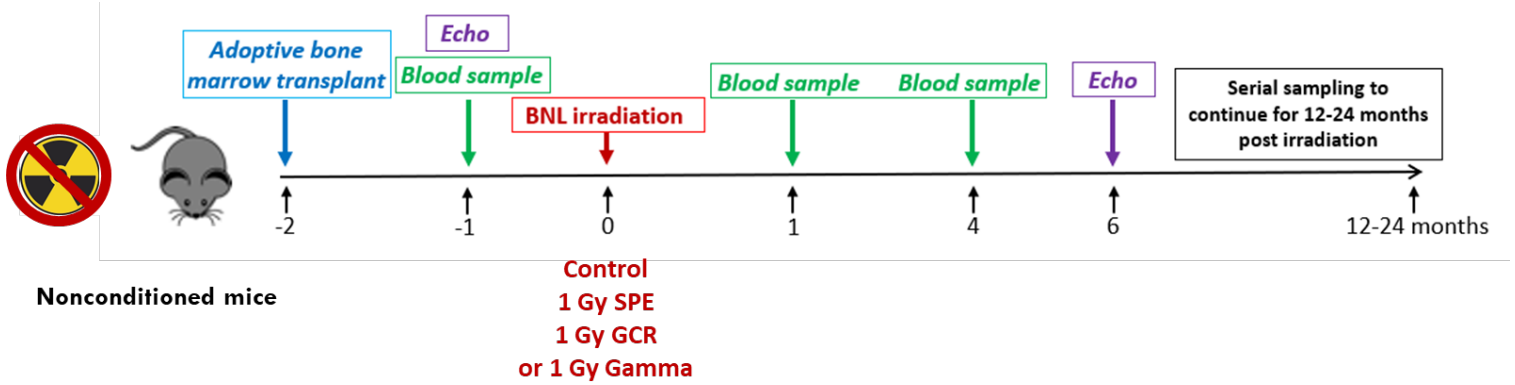


Understanding the sex-specific consequences of ionizing radiation on clonal hematopoiesis

PI: Dr. Kenneth Walsh

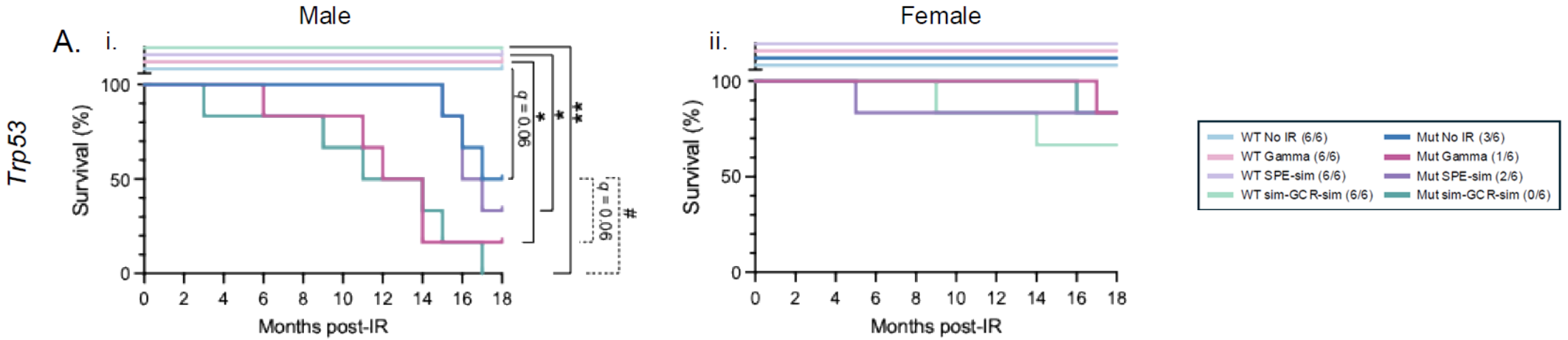
Objective:

- Studying the effect of radiation on driving clonal hematopoiesis (CHIP), specifically TP53, PPM1D, TET2, and DNMT3A driver genes due to their association with CVD and cancer.
- Easily measurable and could inform risk estimates but also post-mission surveillance for both cancer and cardiac.



Observations:

- Some forms of clonal hematopoiesis are promoted by space radiation, with striking effects on morbidly and mortality (e.g. TP53)



Somatic Mosaic Loss of Y (mLOY)

The New York Times

As Y Chromosomes Vanish With Age, Heart Risks May Grow

A study of mice might explain why.

Share full article



A scanning electron micrograph of human X and Y
suggests loss of the Y chromosome could explain m
Associates/Science Source

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SCIENCE

The Disappearing Y Chromosome

It's surprisingly common for men to start losing entire chromosomes from blood cells as they age.

By Sarah Zhang

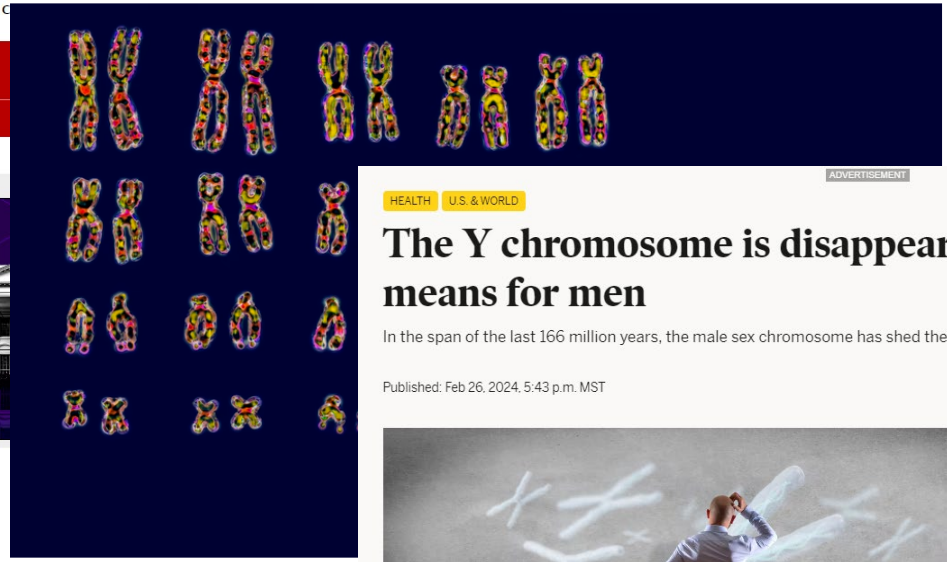
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Health





man chromosomes, with a pair of XY and XX chro

Y chromosome linked to cancer and death risk in men

22 October 2014



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HEALTH U.S. & WORLD

The Y chromosome is disappearing. Here's what it means for men

In the span of the last 166 million years, the male sex chromosome has shed the majority of its 1,600 genes

Published: Feb 26, 2024, 5:43 p.m. MST

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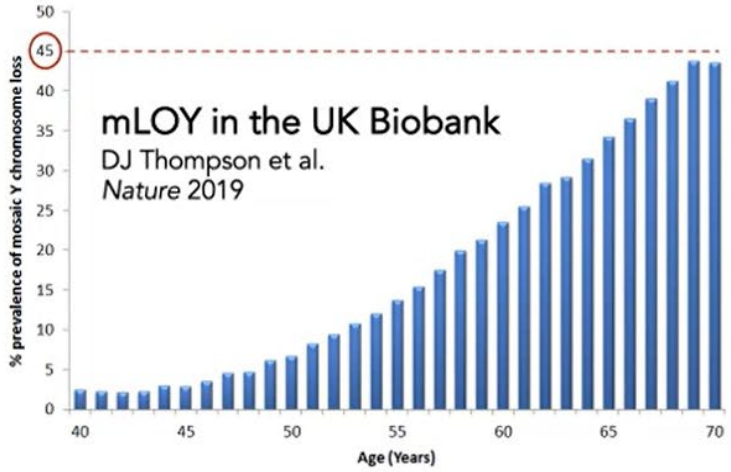
Scientists are monitoring the degradation of the Y chromosome in humans, and explaining what it means for the human race. | Adobe.com

By Alyssa Bradford
Alyssa is a trending desk writer for the Deseret News. She covers health and travel.

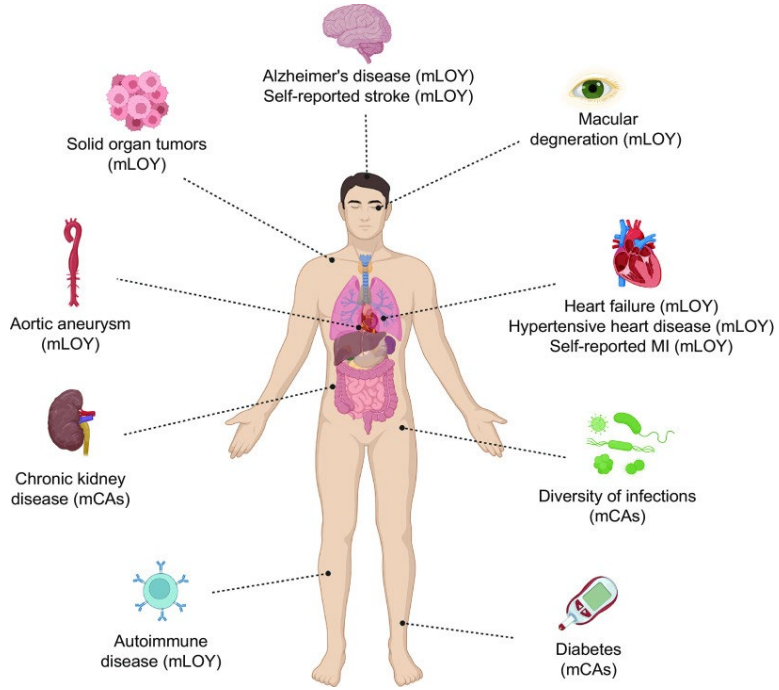
Practice French
Practice German
Practice Italian
Practice Spanish
Practice Portuguese

Somatic Mosaic Loss of Y (mLOY)

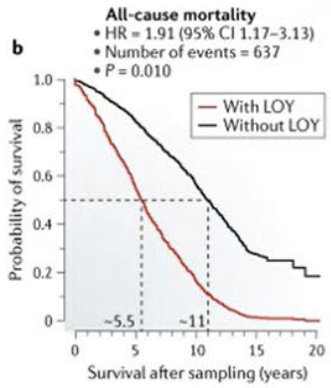




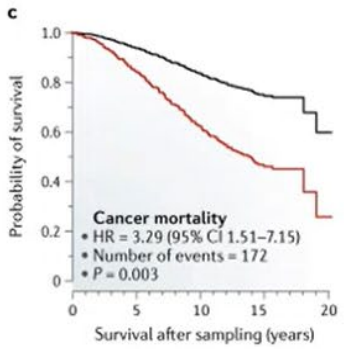
~45% mLOY by age 70 in males



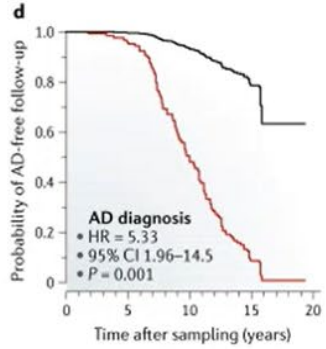
All-cause mortality



Cancer mortality



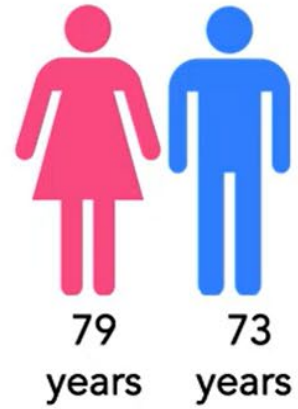
AD diagnosis



From Jobling and Tyler-Smith *Nat Rev Genet* 2017; 18:485-497

"I'm quite certain that the loss of the Y chromosome with age explains a very large proportion of the increased mortality in men, compared to women."

Lars Forsberg, Uppsala Univ.
New York Times, 2018



M. A. Evans and K. Walsh Physiological Reviews 103:649-716 (2023)

Understanding the sex-specific consequences of ionizing radiation on clonal hematopoiesis

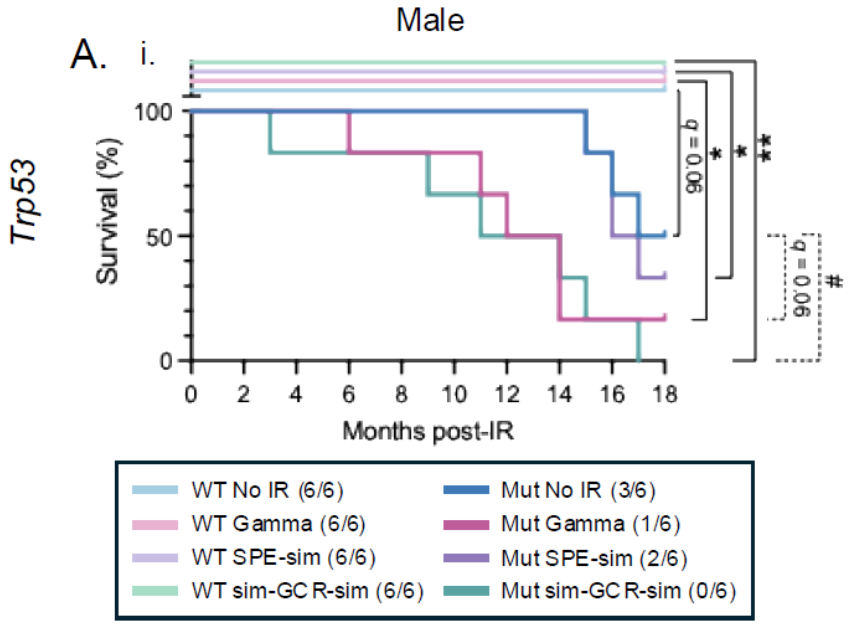
PI: Dr. Kenneth Walsh

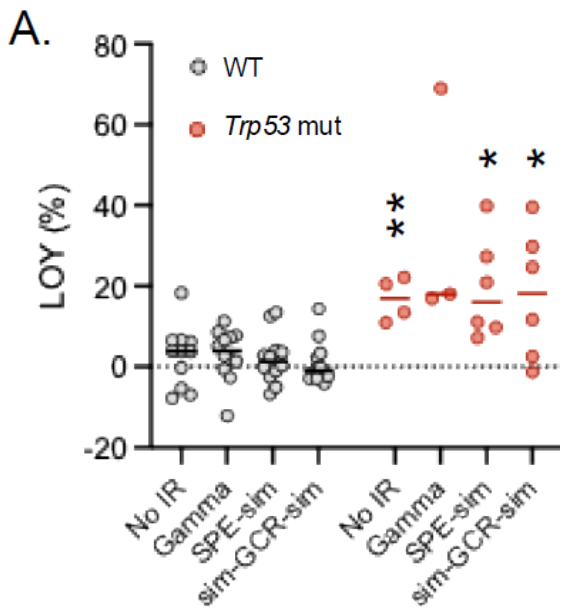
Objective:

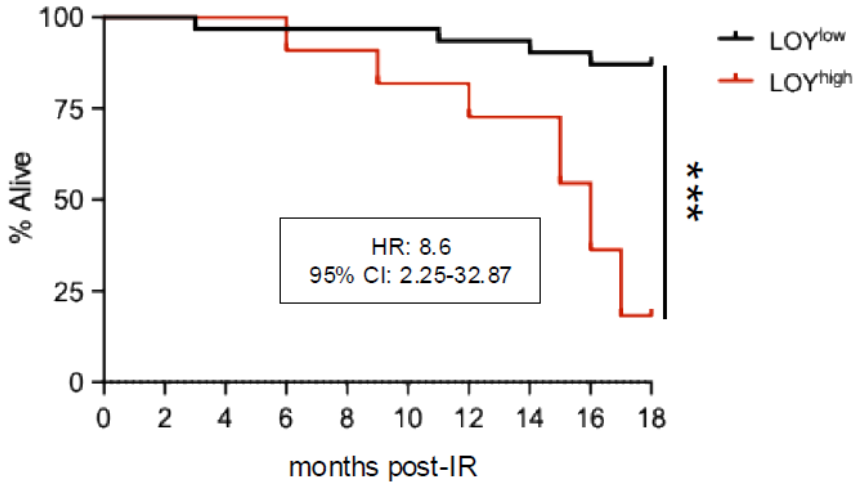
- Studying the effect of radiation on driving clonal hematopoiesis (CHIP), specifically TP53, PPM1D, TET2, and DNMT3A driver genes due to their association with CVD and cancer.
- Studying how the loss of the Y chromosome (LOY), only in male animals, may affect mortality in combination with CHIP and radiation.
- **Easily measurable and could inform risk estimates but also post-mission surveillance for both cancer and cardiac.**

Observations:

- Some forms of clonal hematopoiesis are promoted by space radiation, with striking effects on morbidly and mortality (e.g. TP53)
- Strong male-dependence of space radiation on survival in the TP53 condition may be partly explained by the tumorigenic effects







Persistent radiation-induced multi-system degenerative effects and the accelerated aging phenotype

PI: Jeffrey Willey

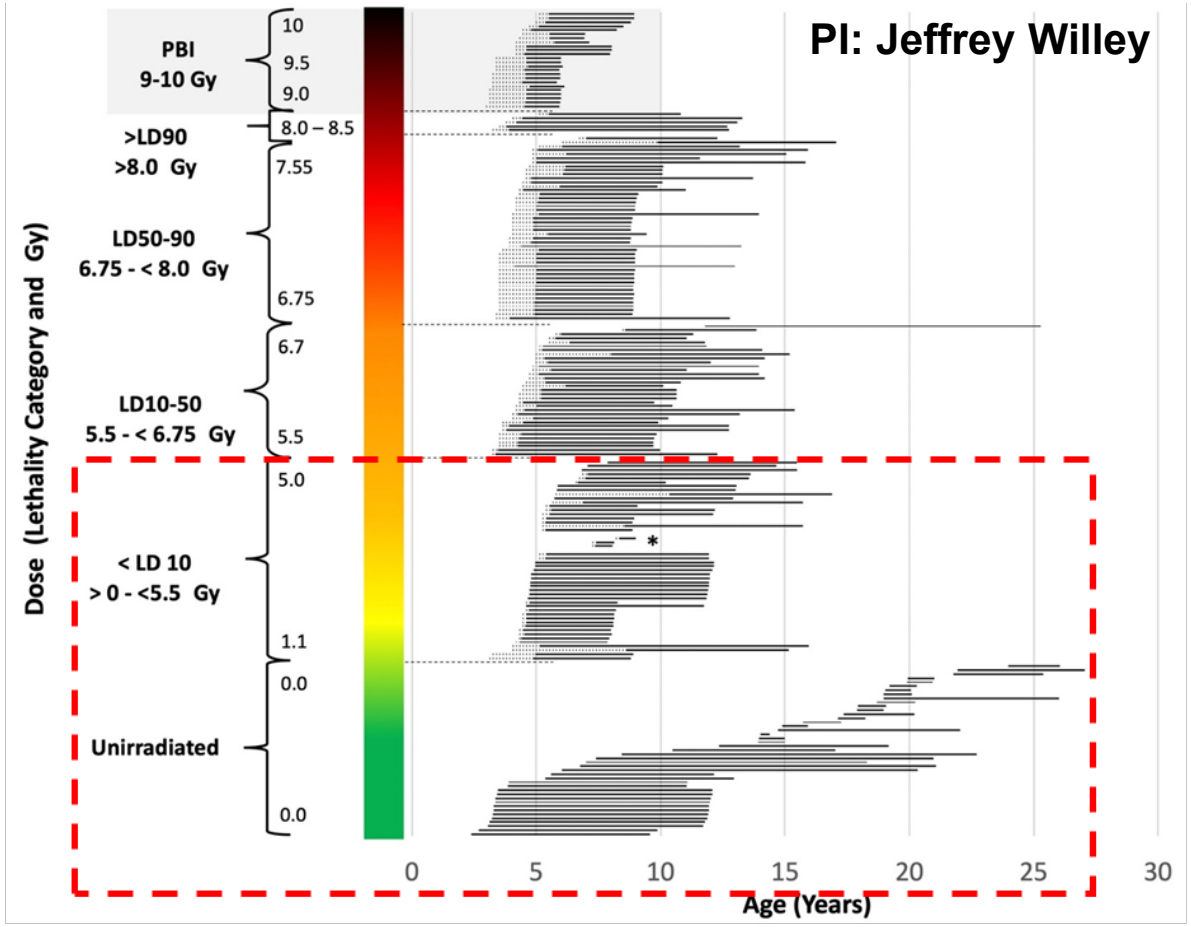
Aims:

1. Determine if IR induces neuroinflammation in NHPs similar to the degree and spatial pattern of rodents as previously studied by the NASA HRP SRE.
2. Determine if IR increases mLOY from bone marrow somatic cells in NHPs and conduct preliminary assessment of the correlation between LOY with cancers and other IR-associated morbidities that are highly prevalent in the RLEC.

- *Depending on results the ability to correlate to findings to cardiac and brain imaging. Possibility of adding CHIP analysis.*

Deliverables:

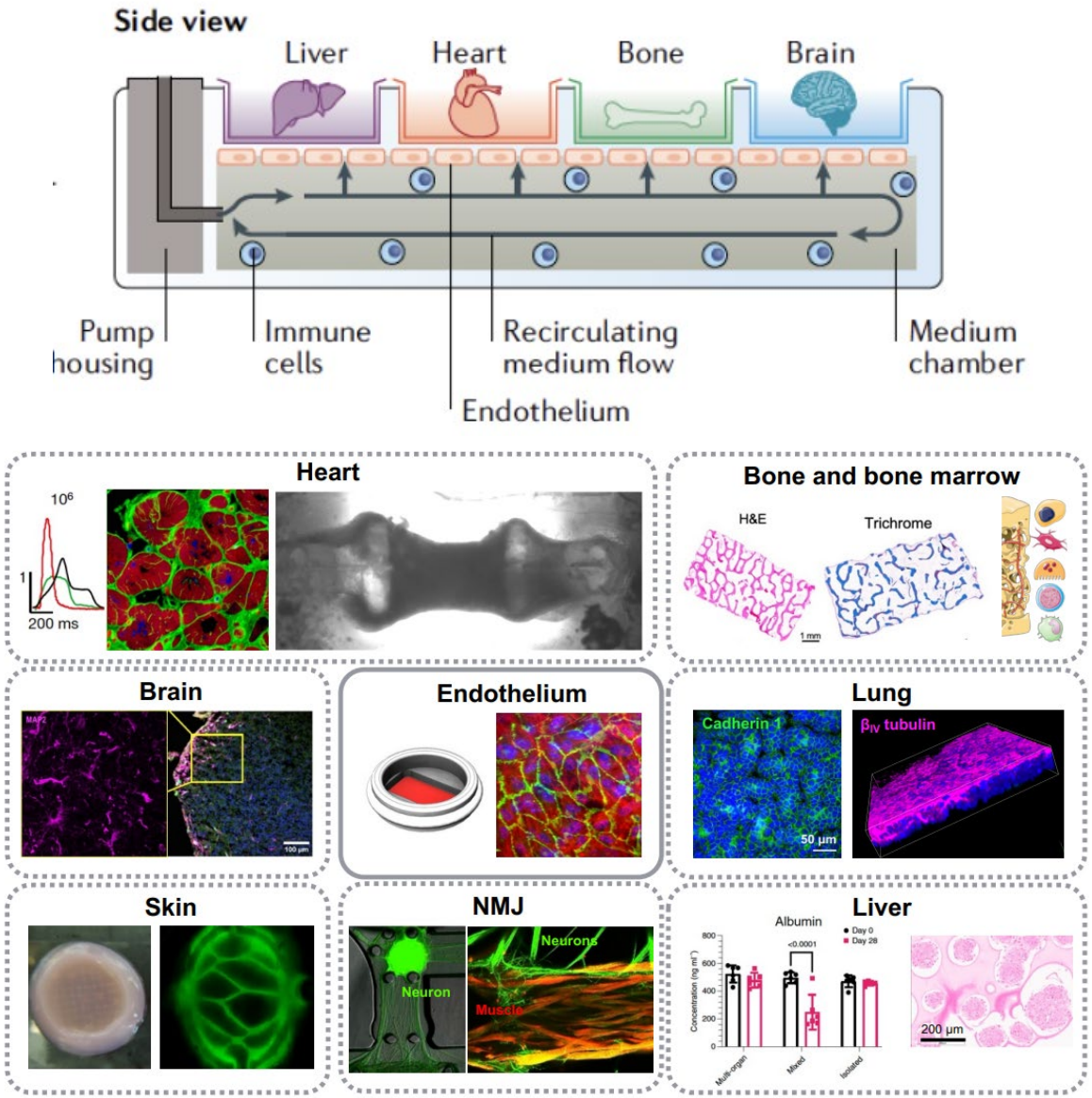
1. Will inform our understanding of neuroinflammation/ Parkinsons risk post-irradiation across species.
2. Sex-difference will be analyzed.
   - In mice, female mice have less neuroinflammation than male mice post-irradiation.
3. Establishment of mLOY in an irradiated NHP.
   - Possibility of incorporating mLOY into LTH modeling efforts.



	Years Observed	Years Post-WBI	Radiation Dose Range (Gy)
Females (n=12)	1.9 – 13.7	2.8 - 13.1	0 - 5.5
Males (n=18)	1.4 – 10.0	1.4 - 11.0	0 - 5.5

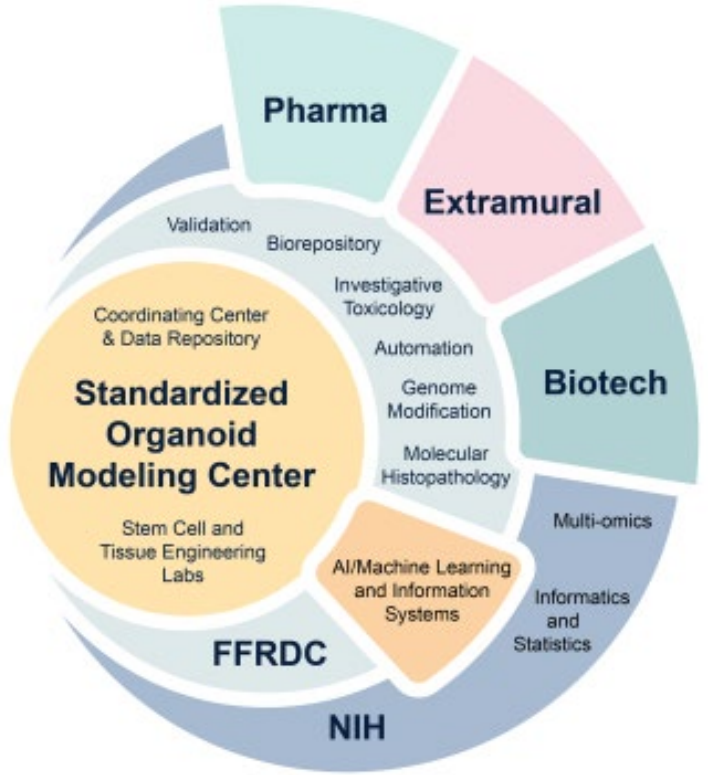
Advanced biological systems/tissue chip radiation dose response

PI: Drs. Sharon Gerecht and Gordana Vunjak-Novakovik - TRISH Funded









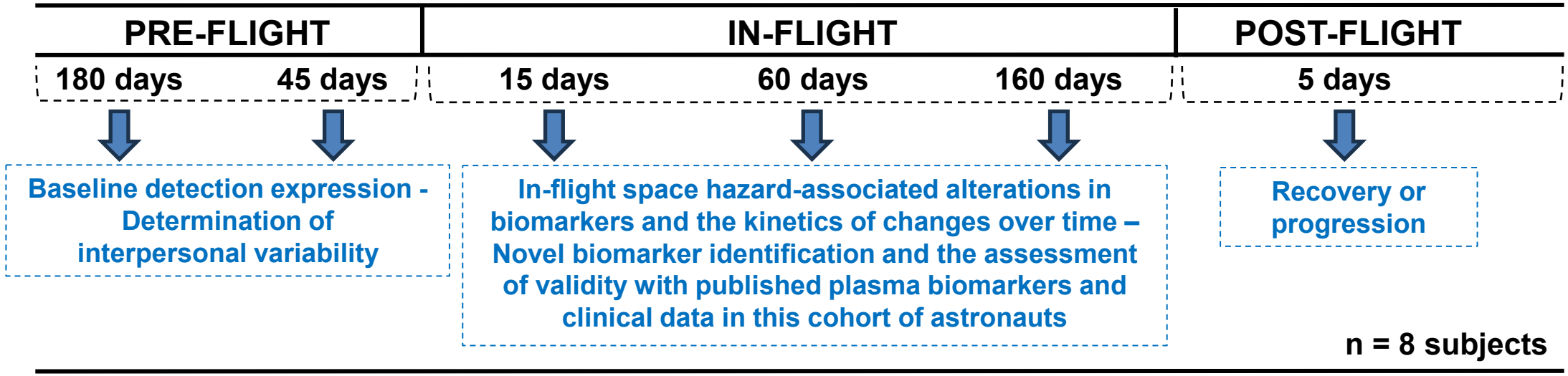
The SOM Center connects resources across the NIH with other federal agencies and industry partners to foster collaboration and accelerate NAMs technologies for the greater scientific community.

Identification of Transcriptomic and Proteomic Biomarkers in Plasma and Urine Samples of Astronauts in Cardio-Ox Study

PI: David Goukassian / Icahn School of Medicine at Mount Sinai

Experimental Design

Utilizing CardioOx Study samples



PLASMA

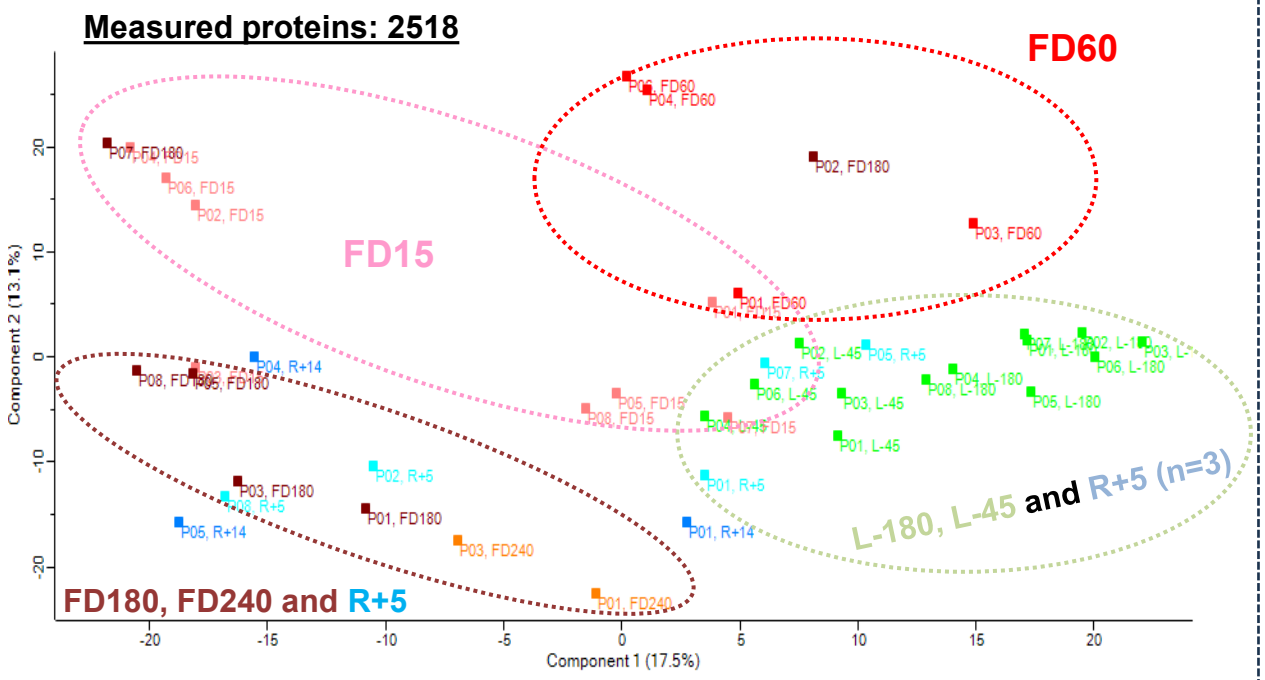
Cell Free Mitochondrial DNA (cf-mtDNA)
Cell Free DNA (cf-DNA
Cell Free RNA (cf-RNA)

PLASMA and URINE

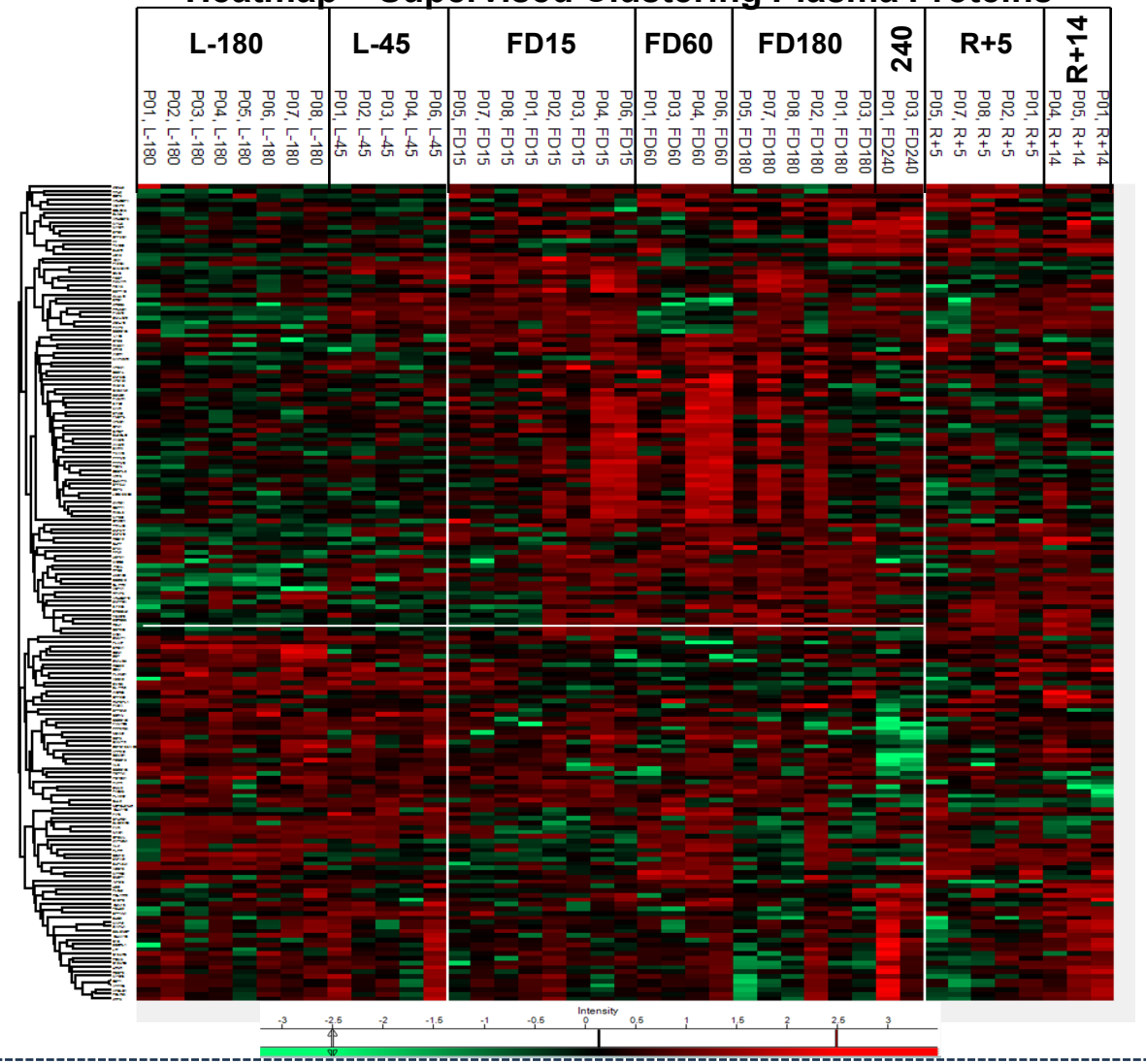
In small extracellular vesicles (sEV)
RNA and Protein Biomarkers:
Messenger – mRNA
Small non-coding – miRNA, snRNA, snoRNA, tRNA
Long non-coding – lncRNA
Proteins

Identification of Transcriptomic and Proteomic Biomarkers in Plasma and Urine Samples of Astronauts in Cardio-Ox Study

PCA Plot for Supervised Clustering – Plasma Proteins



Heatmap – Supervised Clustering Plasma Proteins



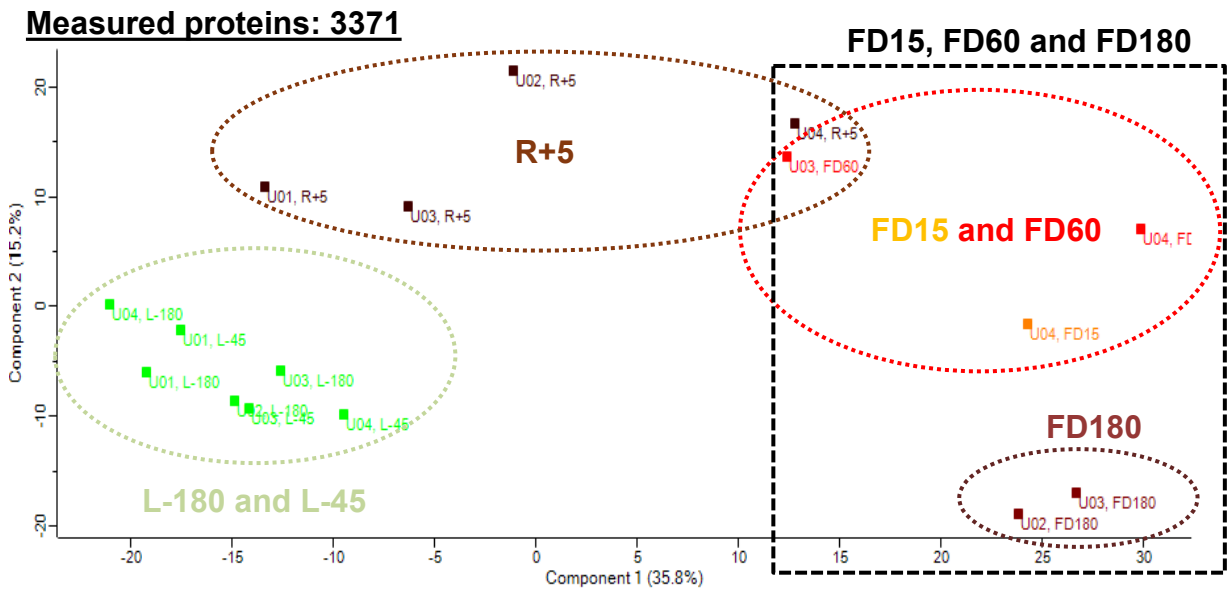
Top 3 upregulated proteins in plasma L-180 vs. Fs and Rs

FD15	FD60	FD180	FD240	R+5	R+15
ERCC6L2	MTREX	ERCC6L2	ERCC6L2	MTREX	MTREX
84-fold	163	245	71	222	499
ICA1	LOC400499	RSU1	TSH2	ERCC6L2	ERCC6L2
63	13	5	5	108	209
SEPTIN2	SBNO2	SBNO2	SHC	PLPP7	LOC400499
6	10	4	2	5	8

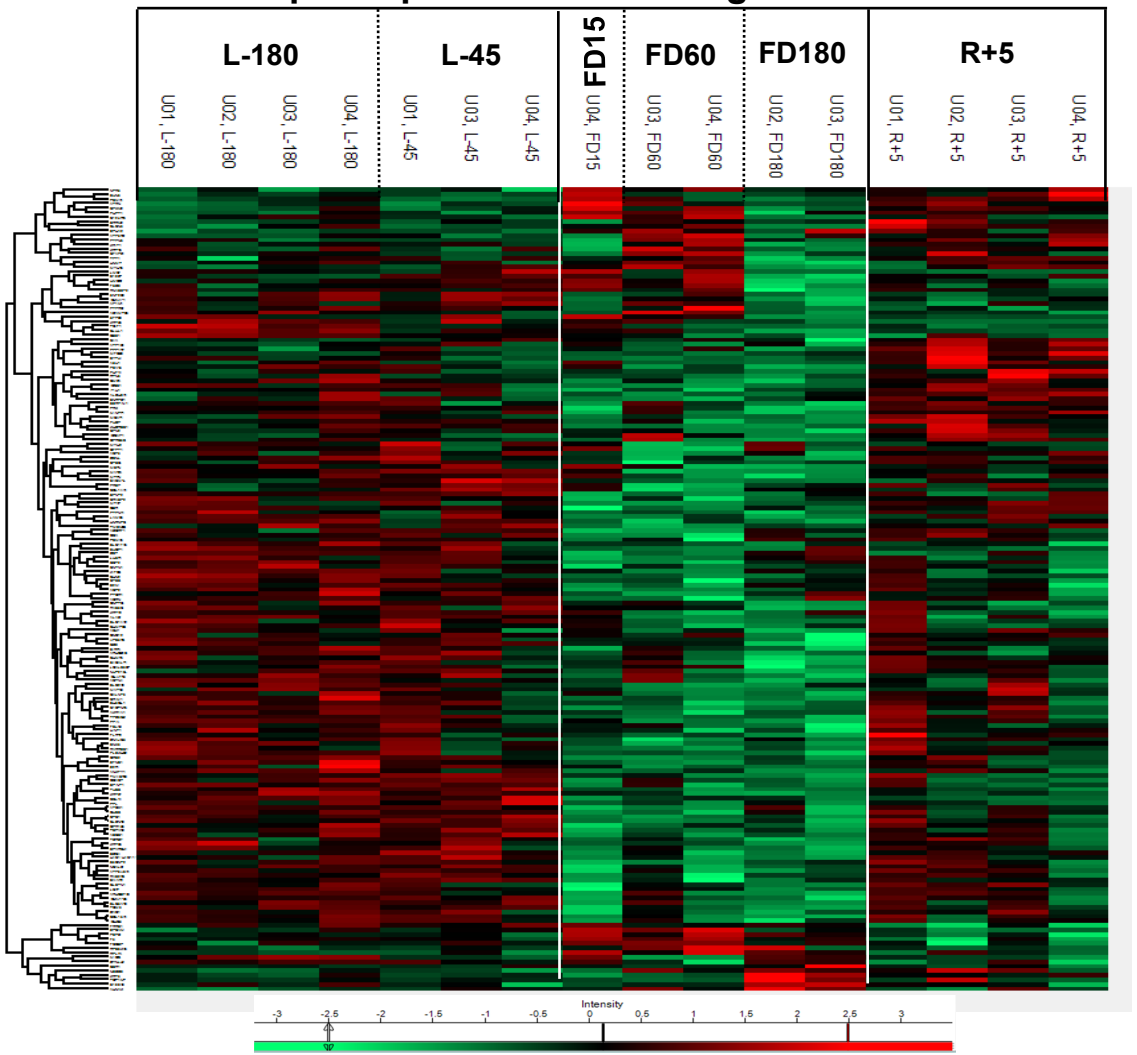
The **ERCC6L2** gene (**DNA excision repair protein ERCC-6-like 2 or RAD26-like**) encodes a protein involved in DNA repair, especially at replication stress points and centromere stability, by promoting DNA end-joining and restricting DNA end resection **during double-strand break repair**. The **ERCC6L2** gene has been linked to **an increased risk of clonal evolution in affected patients**. **MTREX** - involved in DNA damage responses RNA catabolic process, and maturation of 5.8S rRNA. Biomarker of amyotrophic lateral sclerosis.

Identification of Transcriptomic and Proteomic Biomarkers in Plasma and Urine Samples of Astronauts in Cardio-Ox Study

PCA Plot for Supervised Clustering – URINE Proteins



Heatmap – Supervised Clustering URINE Proteins



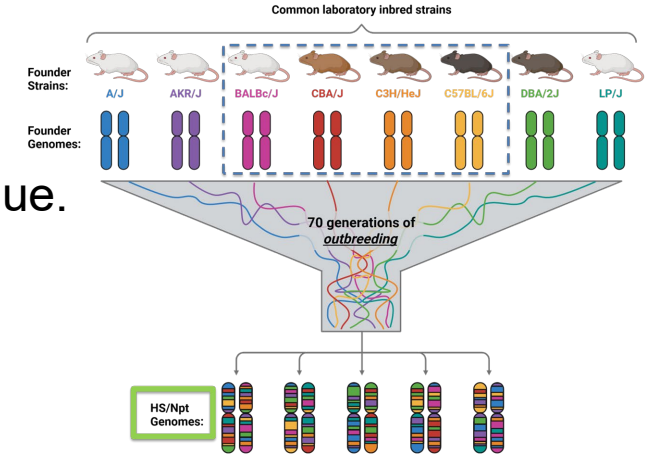
Top 3 upregulated proteins in URINE L-180 vs. Fs and R

FD15	FD60	FD180	R+5
ARTN	IQGAP1	AHNAK	PSMA1
263-fold	167	174	100
PSMA1	RPL7A	RPL7A	IQGAP1
256	34	9	85
NPR3	PTPRO	PEPD	MFGE8
36	15	3	28

The **PSMA1** is a critical component of the 20S proteasome, a multi-protein complex responsible for degrading unneeded or damaged proteins inside a cell. **Gastric cancer:** High **PSMA1** expression is linked to poor prognosis, promotes the proliferation, migration, and invasion of cancer cells. **Lung cancer:** Overexpression of **PSMA1** is associated with poor prognosis and increased tumor growth in lung squamous cell carcinoma. **Triple-negative breast cancer (TNBC):** a circular RNA derived from **PSMA1** (circPSMA1) promotes tumorigenesis, metastasis, and migration. **Colon cancer:** High expression of **PSMA1** may be a biomarker for early-stage colon cancer. **RPL7A -** encodes ribosomal protein L7a, a component of the large 60S ribosomal subunit essential for protein synthesis. **Clinical Relevance** - up-regulation by ethanol in breast cancer, may influence translational regulation and contribute to tumor progression and metastasis.

Radiation Quality Study in HS-NPT Outbred Mice

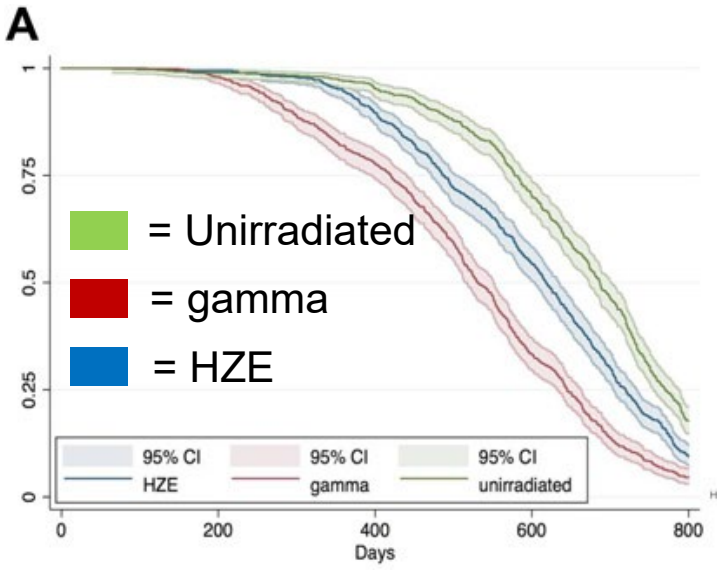
Host genetic factors dictate risk for tumor development following radiation exposures, regardless of radiation quality.

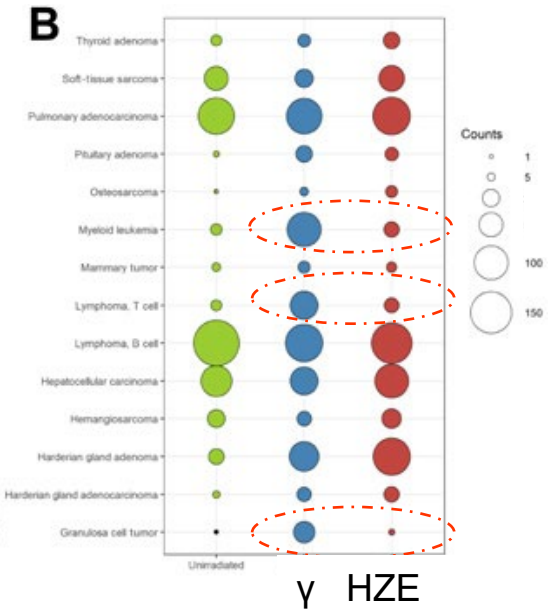


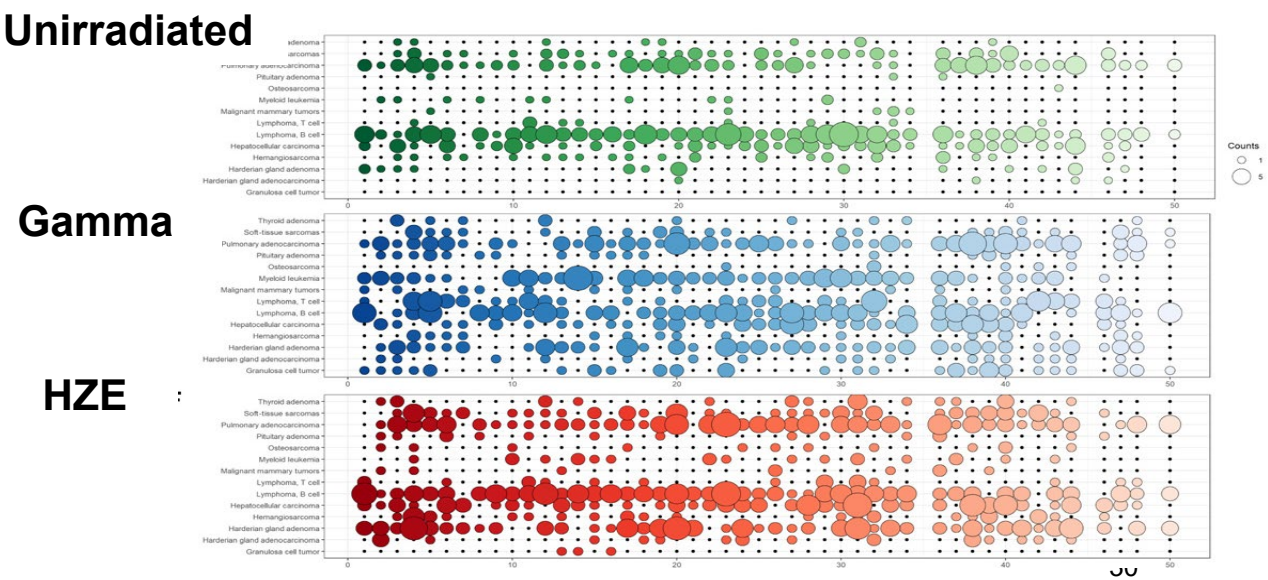
Main take-aways from a genetically diverse population:

- Spectrum of tumor histotypes observed in particle radiation exposed mice is not unique.
- Genetic susceptibility to certain tumor types. (cyclical and clustering of tumors)
- Genomic mapping in outbred mice reveals overlap in genetic susceptibility for HZE ion- and γ-ray-induced tumors

Incidence of Specific Tumor Histotypes

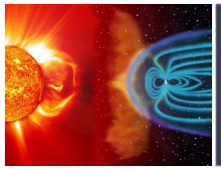






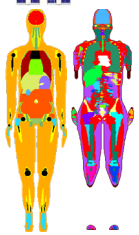
Edmondson EF et. Al. doi: 10.1126/sciadv.aax5940. PMID: 32494593;

Radiation Risk Assessment Model Framework

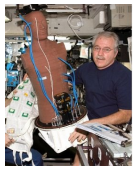


Environment Models





Vehicle and body shielding



Crew dosimetry

MERA Risk Projection Models

Cancer (includes NSCR)	CVD	CNS

- **Multi-model ensemble methodologies**
- **Personalized risk factors**
- **Lifetime risk estimates (REIC/REID)**
- **Additional risk metrics**
- **Combined spaceflight hazards**

Radiation transport models

HZETRN2020

Mission-dependent sex and tissue specific particle energy spectra

Radiation quality & dose-rate
NSRL data

Epidemiology
LSS cohort
Million Person Study

Background disease and survival rates

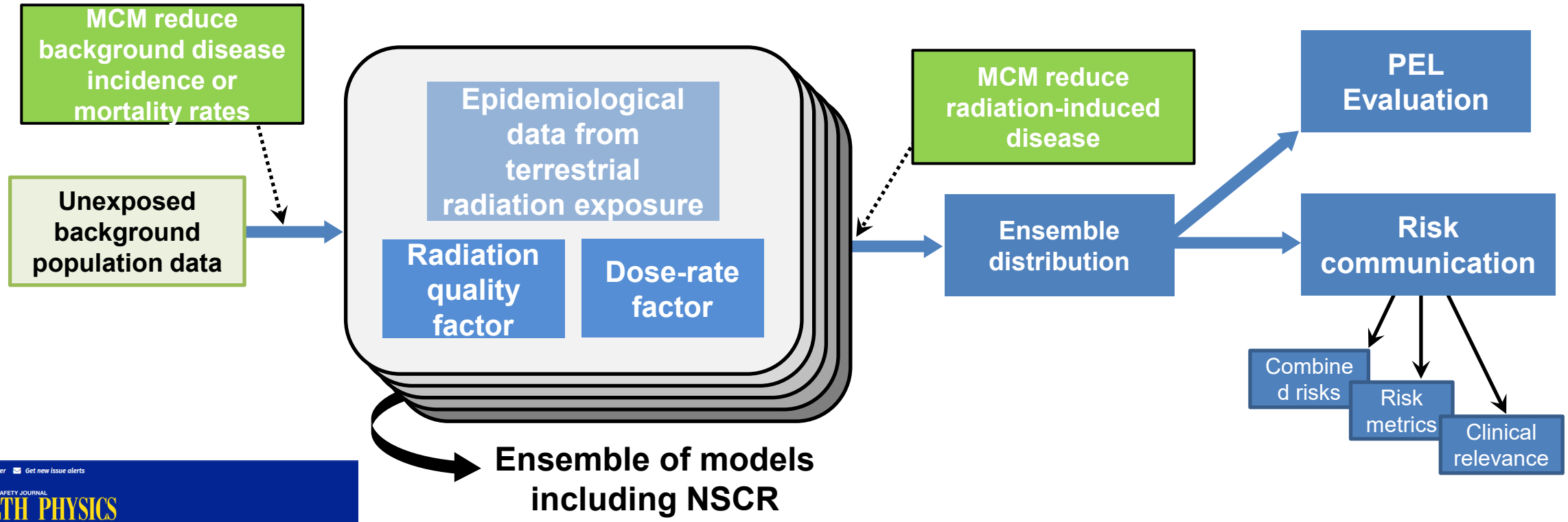
Personalized factors

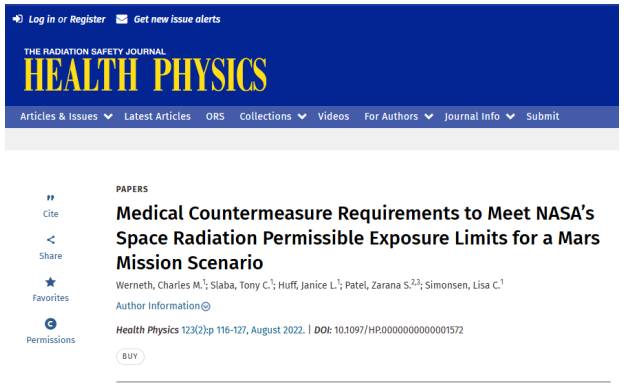
Countermeasure effects

MERA technical content

Framework for Capturing Medical Countermeasures in the Space Radiation Risk Model

Using values from experimental studies and/or clinical studies the reduction in disease can be factored into our models to measure the impact on mortality, incidence, and PMD.




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PAPERS
Medical Countermeasure Requirements to Meet NASA's Space Radiation Permissible Exposure Limits for a Mars Mission Scenario
Werneth, Charles M.[1]; Slaba, Tony C.[1]; Huff, Janice L.[1]; Patel, Zarana S.[2,3]; Simonsen, Lisa C.[1]
Author Information
Health Physics 123(2):p 116-127, August 2022. | DOI: 10.1097/HP.0000000000001572
BUY

Notional diagram of space radiation risk model framework to assess and communicate the increased risks of radiogenic cancers, cardiovascular disease, and late neurogenerative diseases from mission exposures.

Cancer Risk Approach Plan

	Risk Characterization	Countermeasure (CM) Development, Evaluation, Validation, and Integration
HRR Knowledge Gap	**Cancer-103:** Determine the effects of **radiation quality** on cancer initiation, promotion, progression. **Cancer-104:** Determine the effects of radiation **dose and dose-rate** on cancer initiation, promotion, progression. Brookhaven National Laboratory **1 NSCR update with Qnew development (2025)** **Cancer-202:** Evaluate the contribution of **genetic background/ diversity** on carcinogenesis risk. **Cancer-203:** Evaluate the **tissue-specific risks** of space radiation exposure on cancer outcomes. **Cancer-204:** Evaluate the **sex-specific risks** of space radiation exposure on cancer outcomes. Brookhaven National Laboratory **2 NPR 8900 Baseline (PEL evaluation) (2025)** **3 NPR 8900.1B Acceptance – Characterization Data (2030)**	**Cancer-403:** Identify and/or develop potential **biomarkers** to support health surveillance and countermeasure implementation. **Cancer-504:** Identify and validate **safe and effective countermeasures** to reduce radiation carcinogenesis. **Cancer-604: Operationalize validated pharmaceutical countermeasures and surveillance technologies** for spaceflight. Brookhaven National Laboratory **4, 8 Clinical Practice Guideline (CPG) Recommendations (2030, 2038)** **5 Countermeasure Identification (2036)** **6 8900 Acceptance - Mitigation Data (2038)** **7 Integrated CM Toolkit (2038)** **9 Fitness for Duty Standard Recommendations (2040)**

Legend: M2M Deliverable; Lunar Deliverable; ISS; Brookhaven National Laboratory; Artemis

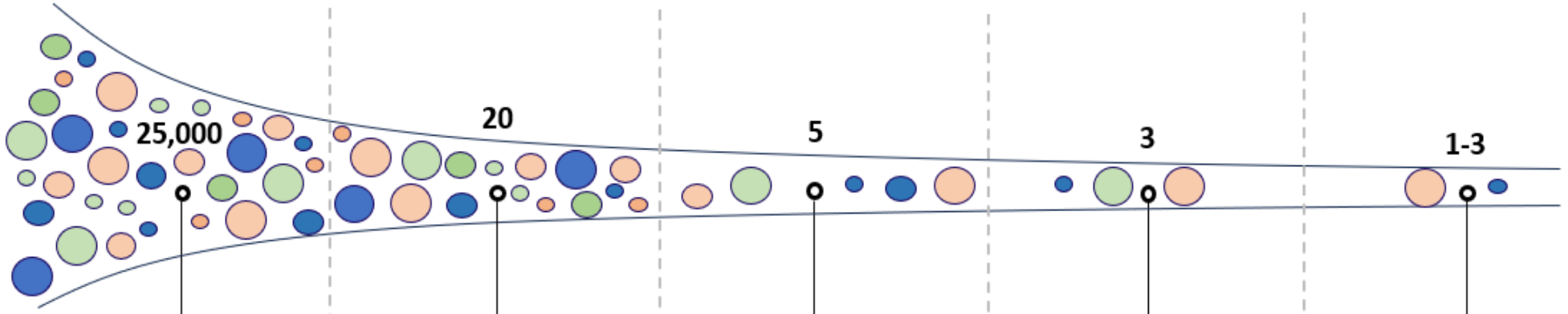
Timeline

1, 2 — 2025 — 3, 4 — 2030 — 5 — 6, 7, 8 — 2038 — 9 — 2040

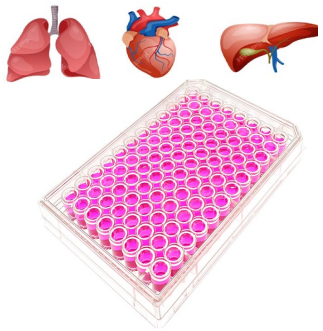
Risk Maps to ESDMD Gap ID # 0308

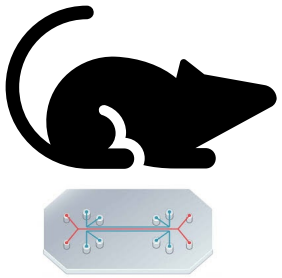
Pharmaceutical Countermeasure Down Selection Approach

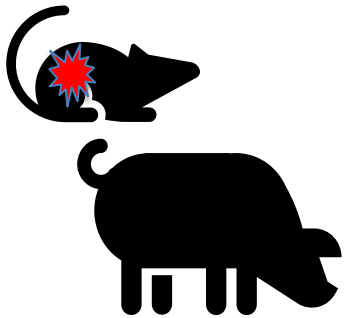
Radiation Countermeasure Downselection Approach

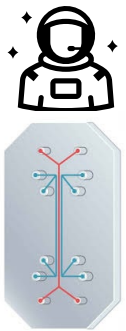


Research Emphasis - 5	Research Emphasis - 5	Research Emphasis – 6	Research Emphasis - 6	Research Emphasis – 7
In vitro	Outbred Study and Tissue Chips	Teratomas and Mini-pigs	Astronaut Tissue Chips (Analog)	Astronaut Flight Studies
Evaluate ≤ 25,000 CM	**Evaluate** ≤ 20 CM	**Evaluate** ≤ 5 CM	**Evaluate** ≤ 3 CM	**Validate** ≤ 3 CM
FDA Approved and IND				

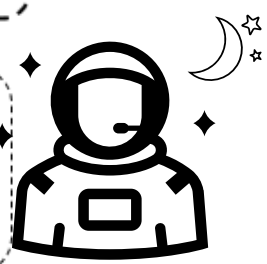








Possibility - Astronaut Tissue Chips (flight)



Overview of SR-Funded Cancer Countermeasures

Drug	FDA status	Model	Radiation	Cancer	Outcome
Aspirin	Approved	APC1638N/+ male mice	**28Si-ions** (10, and 50 cGy)	GI-intestinal, colonic	↓ radiation-induced genomic instability ↓ PGE2 **Does not protect against space radiation-associated tumorigenesis**
Metformin	Approved	APC1638N/+ mice, WT 129/Sv mice	**28Si-ions** (10 cGy), **X-ray** (10 Gy), **33-ion GCRsim** (75 cGy)	GI-colon, Lung,	↓ x-rays, protons, and GCR ions-induced genomic instability, inflammation ↓ **heavy ions-induced GI tumorigenesis**
CDDO	Approved	CDX2PApcflox/+ mice, WT 129/Sv mice; LA-1 mice, CPC;APC mice	**Proton** (2 Gy), **Fe-ions** (1 Gy: 0.2 Gy x 5), **X-ray** (10 Gy), **33-ion GCRsim** (75 cGy)	Lung, Colon	↓ x-rays, protons, and GCR ions-induced DNA damage, inflammation and potential anti-senescence ↓ **proton-induced colon tumorigenesis, reduced invasive carcinomas in both lung and colon models** **Prevents GCR cognitive changes in GCR irradiated female mice**

Future directions •*Post-exposure testing* •*Testing with full GCR* • *Dose response studies*

Implications: Metformin and CDDO as potential radioprotectant, particularly in astronauts, cancer patients undergoing radiotherapy, or populations affected by nuclear accidents

Suman et al.,2021 Life Sci. Space Res.; Suman & Fornace, 2022 Life Sci. Space Res.; Siteni S et al., 2024 PLoS ONE

Sachi Bio – SBIR Phase III

Rapid, Low-Cost Drug Discovery in Space

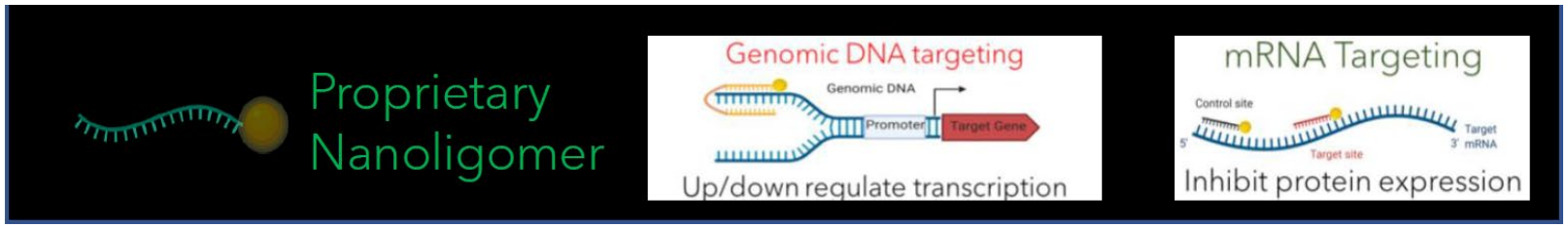
Previous Funding:
- **TRISH**
- **SBIR Phase I-II, IIE**

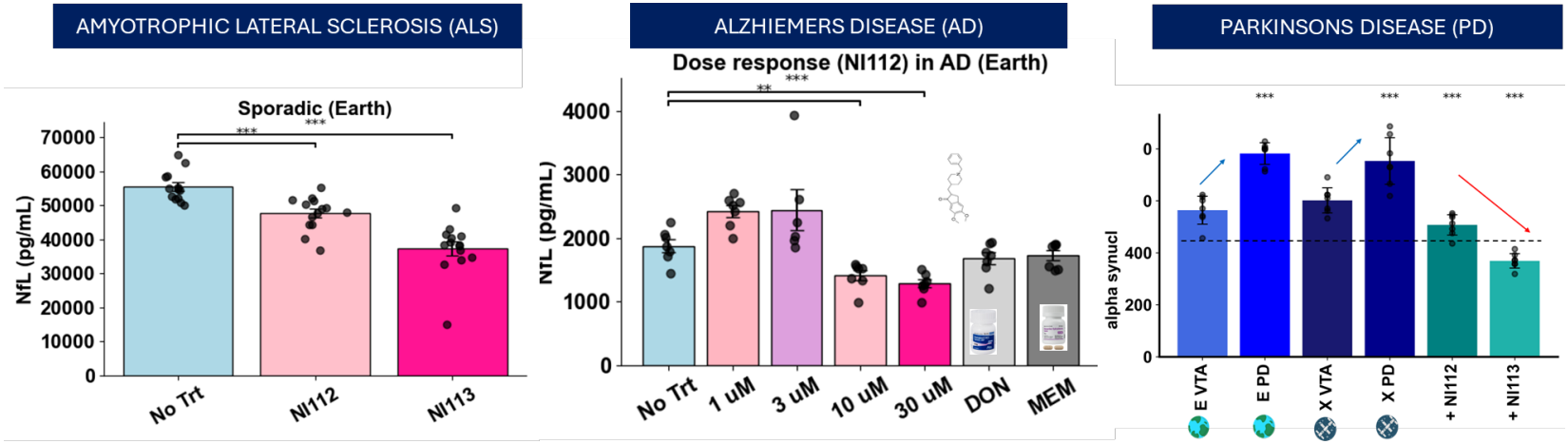
Current Funding:
- **InSpa - funding**
- **SBIR Phase III (SRE funded)**

1.) Nanoligomer Technology
2.) AI capability to accelerate countermeasure target identification

Neuroprotection has been shown:
1. low-dose (0.1 Gy) GCR exposure
2. prion disease model
3. ALS model
4. Alzheimer disease transgenic Model

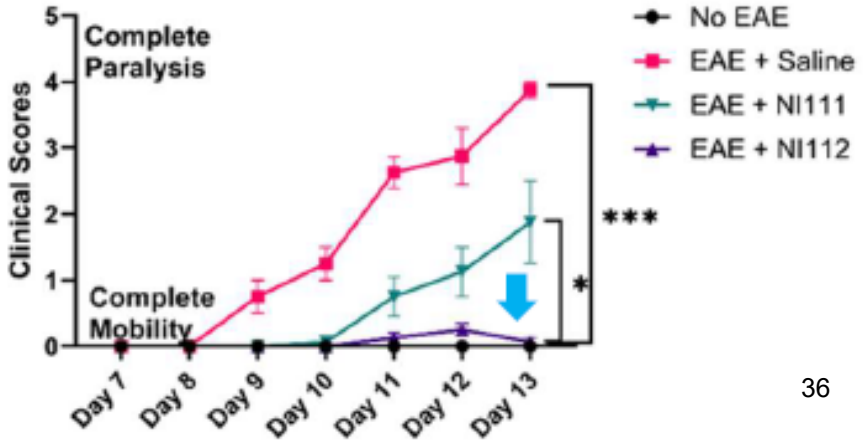
(limited to no toxicity)





DON: Donepezil is a medication that treats symptoms of Alzheimer's disease like memory loss and confusion
MEM: Memantine is used to treat memory loss which is one of the main symptoms of dementia.

Seeking Compassionate Care use in ALS – have already met with FDA and is putting together IND package.



Sachi Bio – SBIR Phase III

Rapid, Low-Cost Drug Discovery in Space

Mouse models

Dog model

Rat model

PROGRAM	TARGET	THERAPEUTIC AREAS/ INDICATION	DISCOVERY	PRE-CLINICAL VALIDATION	IND-ENABLING	EARLY-STAGE PH 1/2
SB_NI_112 (brain-penetrant)	*nfkb*↓	ALS, neurodegenerative diseases				Targeted 2026

ACS Pharmacology & Translational Science > Vol 7/Issue 11 > Article

Cite Share Jump to Expand

ARTICLE | March 21, 2024

Large- and Small-Animal Studies of Safety, Pharmacokinetics, and Biodistribution of Inflammasome-Targeting Nanoligomer in the Brain and Other Target Organs

Sydney Risen, Sadhana Sharma, Vincenzo S. Gilberto, Stephen Brindley, Mikayla Aguilar, Jared M. Brown, Anushree Chatterjee, Julie A. Moreno*, and Prashant Nagpal*

OXFORD JLB JOURNAL OF LEUKOCYTE BIOLOGY

Journal of Leukocyte Biology, 2025, **117**, qiaf024

https://doi.org/10.1093/jleuko/qiaf024

Advance access publication 27 February 2025

Article

Suppression of NF-κB/NLRP3 by nanoligomer therapy mitigates ethanol and advanced age-related neuroinflammation

Paige E. Anton,[1,2] Shannon Twardy,[1,2] Prashant Nagpal,[3] Julie A. Moreno,[4] Matthew A. Burchill,[5,6] Anushree Chatterjee,[3] Nicolas Busquet,[7,8] Michael Mesches,[7,8] Elizabeth J. Kovacs,[2,9,10] and Rebecca L. McCullough[1,2,5,*]

Research | Open access | Published: 27 July 2024

Nanoligomers targeting NF-κB and NLRP3 reduce neuroinflammation and improve cognitive function with aging and tauopathy

Devin Wahl, Sydney J. Risen, Shelby C. Osburn, Tobias Emge, Sadhana Sharma, Vincenzo S. Gilberto, Anushree Chatterjee, Prashant Nagpal, Julie A. Moreno & Thomas J. LaRocca

Journal of Neuroinflammation **21**, Article number: 182 (2024) | Cite this article

3644 Accesses | **16** Citations | **242** Altmetric | Metric

ACS Chemical Neuroscience

pubs.acs.org/chemneuro Research Article

Targeting Neuroinflammation by Pharmacologic Downregulation of Inflammatory Pathways Is Neuroprotective in Protein Misfolding Disorders

Sydney J. Risen, Sean W. Boland, Sadhana Sharma, Grace M. Weisman, Payton M. Shirley, Amanda S. Latham, Arielle J. D. Hay, Vincenzo S. Gilberto, Amelia D. Hines, Stephen Brindley, Jared M. Brown, Stephanie McGrath, Anushree Chatterjee, Prashant Nagpal, and Julie A. Moreno*

ACS Chemical Neuroscience

pubs.acs.org/chemneuro Research Article

Targeted-Neuroinflammation Mitigation Using Inflammasome-Inhibiting Nanoligomers is Therapeutic in an Experimental Autoimmune Encephalomyelitis Mouse Model

Sadhana Sharma, Sydney Risen, Vincenzo S. Gilberto, Sean Boland, Anushree Chatterjee, Julie A. Moreno, and Prashant Nagpal*

Human organoid and tissue-chip models
(Micro physiological systems (MPS))

Privileged and Confidential

In vitro down selects of FDA-approved drugs – Planned work for cancer countermeasure and Greenstone Biosciences Directed Task

Aims:

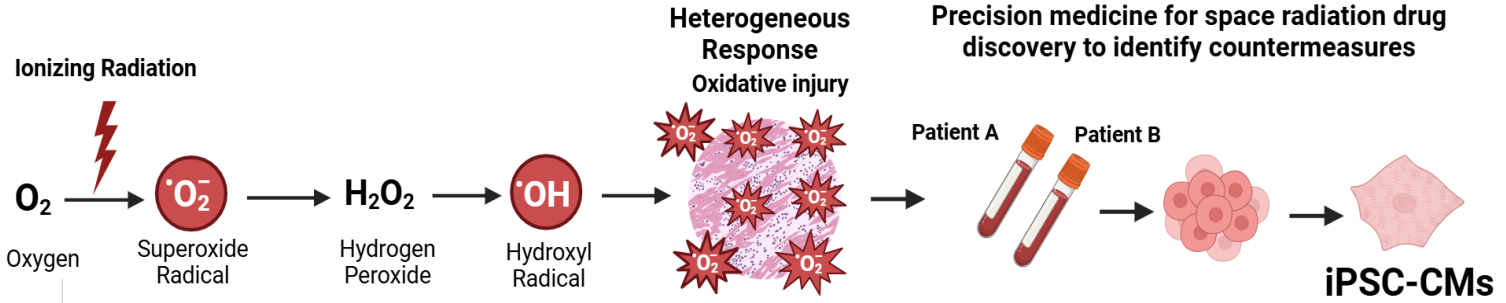
- hiPSCs-derived cardiomyocytes (**iPSC-CMs**) were used to study X-ray-induced damage and screen for protective drugs.
- **Screening process:**

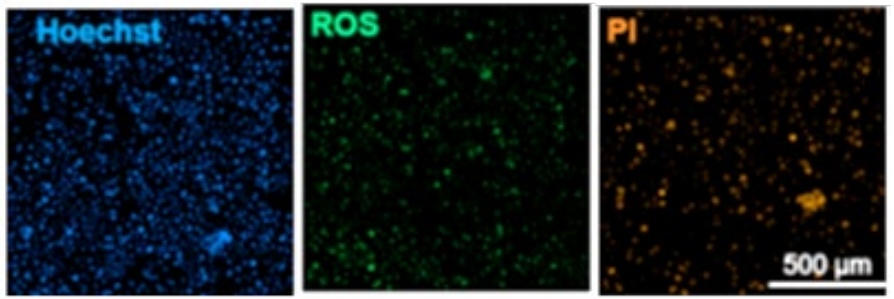
✓ 10 Gy radiation dose was used. 2,320 compounds were screened (post 4 hrs of exposure) .

✓ 1st screening → 44 drug candidates.

✓ 2nd screening (2 and 10 μM concentration) → 23 drug candidates

✓ Final selection (low dose) → **10 reproducible and effective drug candidates.**





Ideal drug candidate

↑ cell count (↑ Hoechst)

↓ ROS (↓ CellRox)

↑ cell viability (↓ PI)

		ROS 2μM	ROS 10μM	Cell death 2μM	Cell death 10μM	Pathway	Target	Information
A2149	Bosutinib (SKI-606)	3.68	3.94	3.18	14.55	TGF-β / Smad Signaling	Bcr-Abl	Potent Abl/Src kinases
A4219	Birinapant (TL32711)	24.57	2.46	5.49	11.96	Apoptosis	IAP	Potent XIAP/cIAP1 antagonist
A4377	Evacetrapib (LY2484595)	26.84	3.27	4.37	12.24	Metabolism	CETP	CETP inhibitor,potent and selective
A5133	Irinotecan	38.80	3.09	2.78	29.31	DNA Damage/DNA Repair	Topoisomerase	Topoisomerase I inhibitor
A8307	Crenolanib (CP-868596)	16.40	3.67	5.07	28.42	Tyrosine Kinase	PDGFR	PDGFR-β inhibitor, potent and selective
A8406	Dextrose (D-glucose)	1.97	3.35	2.90	17.62	Others	Others	Simple sugar (monosaccharide)
A8434	Flurbiprofen	24.67	3.37	29.33	16.54	Immunology/Inflammation	PGE synthase	Cyclooxygenase inhibitors
A8436	Gabapentin	25.28	4.27	4.69	16.21	Neuroscience	GABA Receptor	GABA enhancer
A8639	Deferasirox	36.53	1.61	4.95	19.91	Cell Cycle/Checkpoint	Cyclin-Dependent Kinases	Oral iron chelator
B2300	Tolvaptan	43.68	6.48	6.59	21.44	GPCR/G protein	Vasopressin Receptor	AVP V2-receptor antagonist
		45.13	11.06	10.53	40.61			

Average of ctrl. Group after IR treatment

Future studies will utilize Fibroblasts, DSB Measurements, and simGCR exposure

In vitro down selects of FDA-approved drugs – Planned work for cancer countermeasure and Greenstone Biosciences Directed Task

Radiation countermeasures for NSRL

			Relative value/cell counts						
			ROS 2μM	ROS 10μM	Cell death 2μM	Cell death 10μM	Pathway	Target	Information
1	A8406	Dextrose (D-glucose)	1.97	3.35	2.90	17.62	Others	Others	Simple sugar (monosaccharide)
2	A8435	Furosemide	27.69	4.08	6.46	15.76	Membrane Transporter/Ion Channel	NKCC	GABA(A) receptors antagonist
3	A8436	Gabapentin	25.28	4.27	4.69	16.21	Neuroscience	GABA Receptor	GABA enhancer
4	A8639	Deferasirox	36.53	1.61	4.95	19.91	Cell Cycle/Checkpoint	Cyclin-Dependent Kinases	Oral iron chelator
5	B2078	Atovaquone	5.83	4.51	2.43	34.11	Microbiology & Virology	Anti-infection	unique naphthoquinone with broad-spectrum antiprotozoal activity
6	B3404	Methylcobalamin	45.49	4.85	6.07	20.63	Others	Others	a form of vitamin B12
7	B6736	Citalopram hydrobromide	43.71	5.33	6.77	27.75	Neuroscience	5-HT Receptor	5-HT uptake inhibitor
8		Genistein							
9		Honokiol							
10		Genistein derivative (GSB)							
11		Honokiol derivative (GSB)							
12		Metformin							
13		Quercetin							
14		NAC							
15		CDDO							
16	B2284	Fostamatinib		167 (902.8 ctrl)		268 759.9 ctrl	Tyrosine Kinase	Spleen Tyrosine Kinase (Syk)	Spleen tyrosine kinase (Syk) inhibitor
17	B6185	ACP-196 (acalabrutinib)		1069 1817 ctrl		489 1143.5 ctrl	Angiogenesis	BTK	Irreversible BTK inhibitor
18	B4800	Defactinib		958 1694.9 ctrl		686 1845.6 ctrl	Tyrosine Kinase	FAK/Pyk2	FAK phosphorylation inhibitor
19	A3727	Pitolisant		185 391.4 ctrl		134 308.6 ctrl	Neuroscience	Histamine H3 receptor	Nonimidazole inverse agonist
20		Control (no treatment)							
			45.13	11.06	10.53	40.61			

Average of ctrl. Group after IR treatment

Two days pre-treatment
IR (4 hrs post 10 Gy)-no replicates

GREENSTONE BIOSCIENCES

NBISC Sample Collection

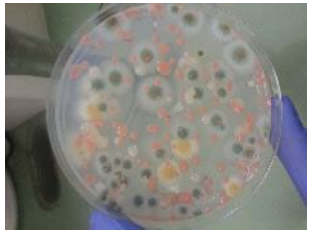
100,000+ Non-Human Biospecimens

- Mouse, Rat, Quail, Bacteria
- Spaceflight
- Simulated Microgravity Ground Analog
- Space Radiation Ground Analog
  - Minipigs
- Samples from 1974

Tissue Types
Blood, Heart, Lymph nodes, Spleen
Caecum, Colon, Duodenum, Gastrointestinal Tract, Ileum, Intestine, Jejunum, Pancreas, Stomach
Adrenal glands, Liver, Salivary glands, Thymus, Thyroid
Bladder, Fecal pellets, Kidney
Adipose, Skin, Whiskers
Adductor longus, Diaphragm, Extensor digitorum longus, Gastrocnemius, Plantaris, Soleus
Brain, Eyes, Hypothalamus, Pituitary
Ovary, Uterus, Testes
Esophagus, Lung, Trachea
Calvaria, Femur, Humerus, Jawbone, Parietal bone, Pelvis, Ribs, Tail, Tibia, Vertebrae
Adrenal, Kidney, Liver, TA, EDL, Eye, Gastrocnemius, Quadriceps, Soleus








NBISC Sample Collection

Biospecimen search

Biospecimen request and award process for biosciences researchers worldwide

Search NASA Life Sciences Portal

Submit request form

Receive confirmation of request and sample availability

Receive instruction form to propose details

Award Criteria

- Requestor must be fully funded
- Approved proposals are merit based
  - Scientific Significance
  - Experimental Design
  - Innovation
  - Qualifications
  - Scientific Environment

Receiving Tissues

- PI completes Research Data Sharing Agreement
- NBISC coordinates shipment to PI
- Award process typically completed in approximately six weeks

NASA Biological Institutional Scientific Collection

OPEN SCIENCE FOR LIFE IN SPACE

Space Radiation Samples at NBISC





Did You know?

The Space Radiation Element is banking current and past funded PIs samples.

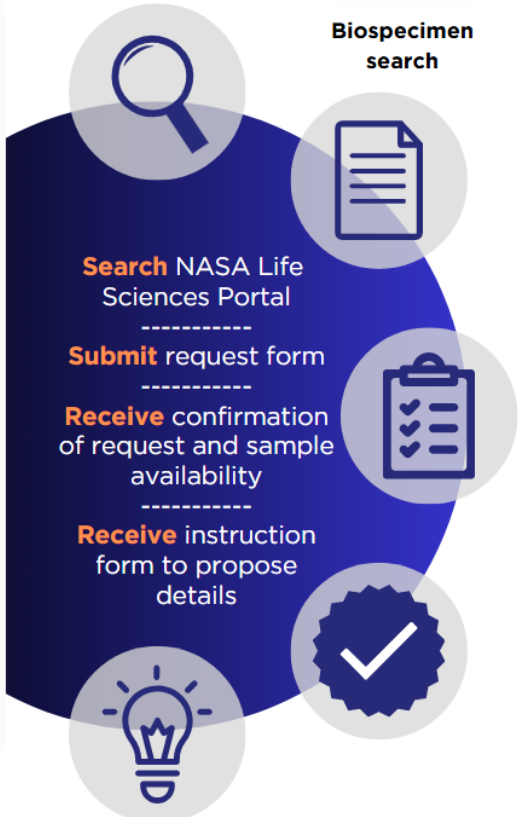
These samples can be requested and are free* once approved.



*Associated shipping charges may apply

How do I request tissues?

Biospecimen search



Broaden your experimental repertoire to include **spaceflight and space radiation** samples!

Samples Available

Blakely Collection

Female CB6F1/Hsd mice tissues (Gross Lesions, Harderian Glands, Brain, Heart , Eye globe, Kidney, Lung, Liver, Spleen, Mammary Gland, Skin, Gonads-ovary, Tail Snip, Bone Marrow, Intestine) were collected 16 months post exposure of different Heavy ion schemes including Si/Ti/Fe, Ti/Si, Ti/Fe, H/Si/Fe, and more. Paraffin embedded, slides, and frozen tissues are available.

Dynan Collection

Male and female C57 mice treated with 28Si (0.4, 0.75Gy), Simplified GCR sim (0.75, 1.5Gy), gamma-rays (0.75, 1.5), Mock-IR, with lung tissues (embedded) and flash frozen livers collected at 1, 6, and 18 months post irradiation.

Space Radiation Samples at NBISC







Samples Available in 2025

Cornforth Collection

Clones from h-tert- immortalized fibroblast cell line that were exposed to 1Gy Fe 1GeV or cesium 1 &4 Gy. Using mFISH 40% of clones have aberrations and 60% do not.

Wyrobek Collection

Tissue samples and experimental data collected in twelve large NASA funded experiments on rats and mice that were performed at LBL from 2008 to 2022.

The Wyrobek archive consists of flash frozen tissue (brain subregions and somatic tissue) stored at -80C (~13,000 samples) and fixed brain tissue blocks and sections stored at -20C (paraffin embedded or OCT) from ~700 rodents. Each tissue sample is electronically linked to corresponding animal-specific information on exposure regimen, behavior testing, molecular profiles, and immunohistochemical findings.

Greg Nelson Collection

Available in 2025
Flash frozen brain regions from female and male mice irradiated acutely with the 33-ion GCRsim field at doses of 0, 15, 25, 50 and 75 cGy complemented by a 2 Gy acute exposure to 137-Cs gamma rays.
Male mice exposed to 50cGy GCRsim (sham, acute, and fractionated regimens) and 2 Gy fractionated gamma rays.

Broaden your experimental repertoire to include spaceflight and space radiation samples!

Learn more!

About NBISC

Janice.Zawaski@NASA.gov
Jordan.R.Rhone@NASA.gov





Funded by: Human Research Program (HRP) and Biological and Physical Sciences (BPS)



NASA Space Radiation Element's **Biospecimen & Tissue Sharing & Collection Program (BTSC)**







Thank you for your attention!

Questions?





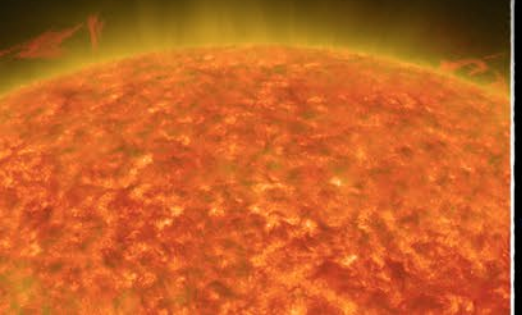
Backup Slides

Space Radiation Element (SRE)

1

Space Radiation

Invisible to the human eye, radiation increases cancer risk, damages the central nervous system, and can alter cognitive function, reduce motor function and prompt behavioral changes.



Human Factors & Behavioral Performance Element (HFBP)
HHC

SRE (Possible confounder of SR effects)

2

Isolation and Confinement

Sleep loss, circadian desynchronization, and work overload may lead to performance reductions, adverse health outcomes, and compromised mission objectives.

Exploration Medical Capabilities Element (EXMC)
HFBP

3

Distance from Earth

Planning and self-sufficiency are essential keys to a successful mission. Communication delays, the possibility of equipment failures and medical emergencies are some situations the astronauts must be capable of confronting.



Human Health Countermeasures Element (HHC)
HFBP

SRE (Possible confounder of SR effects)

4

Gravity (or lack thereof)

Astronauts encounter a variance of gravity during missions. On Mars, astronauts would need to live and work in three-eighths of Earth's gravitational pull for up to two years.

HFBP
HHC

5

Hostile/Closed Environments

The ecosystem inside a vehicle plays a big role in everyday astronaut life. Important habitability factors include temperature, pressure, lighting, noise, and quantity of space. It's essential that astronauts stay healthy and happy in such an environment.





NASA Space Radiation Laboratory

Space Radiation

Invisible to the human eye, radiation increases cancer risk, damages the central nervous system, and can alter cognitive function, reduce motor function and prompt behavioral changes.



HERA

Antarctica (South Pole, Palmer Station)



Isolation and Confinement



CHAPEA (MEA)



NASA Space Radiation Laboratory



HERA

Distance from Earth

Antarctica (South Pole, Palmer Station)





CHAPEA (MEA)



Envihab



Kraken

4

Gravity (or lack thereof)

Astronauts encounter a variance of gravity during missions. On Mars, astronauts would need



NASA Space Radiation Laboratory



HERA

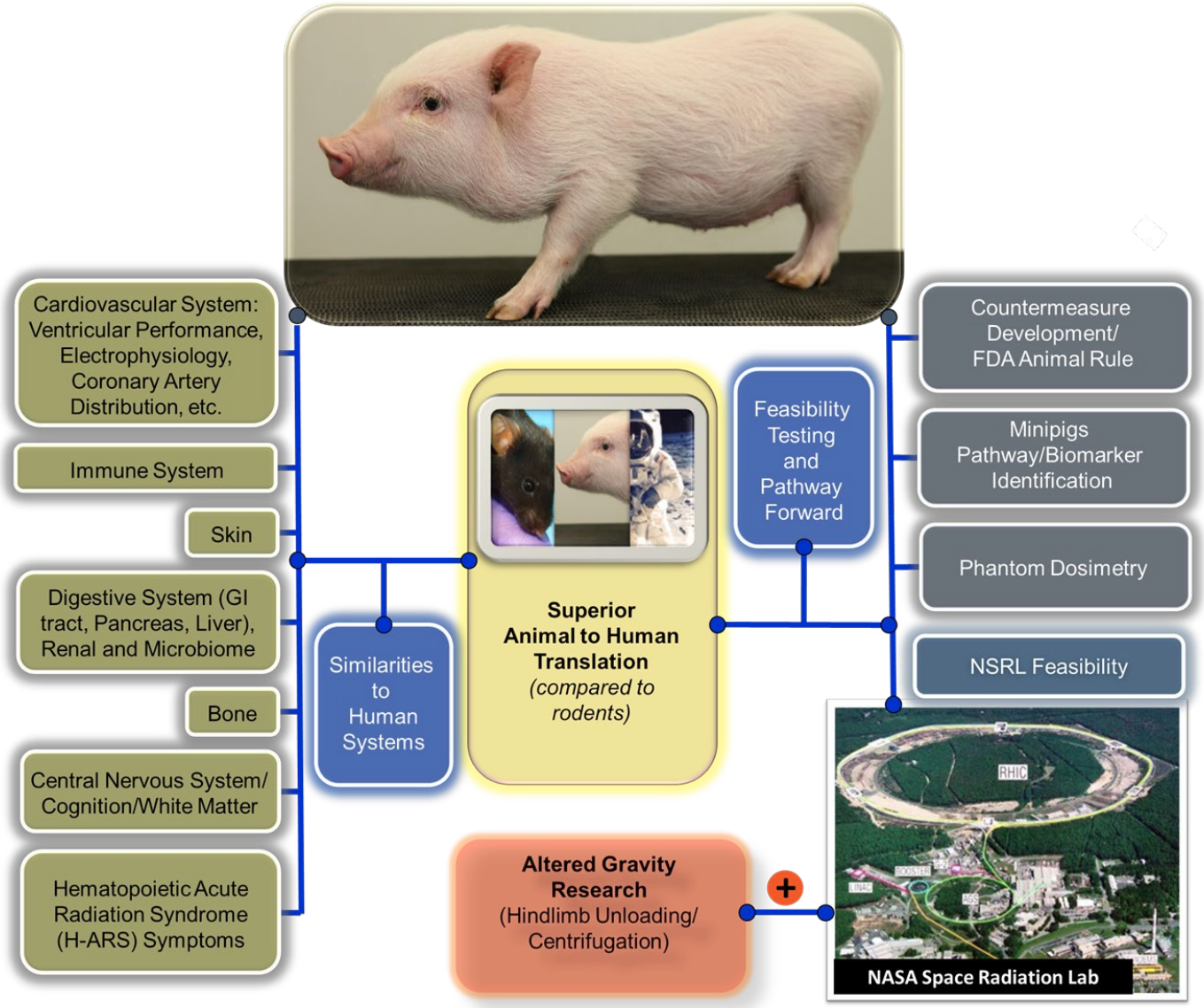
Hostile/Closed Environments

The ecosystem inside a vehicle plays a big role in everyday astronaut life. Important habitability factors include temperature, pressure, lighting, noise, and quantity of space. It's essential that astronauts stay healthy and happy in such an environment.



Mini-pig Advantages for Space Radiation Research

➢ **Mini-pigs offer a translationally relevant platform to study organ-specific radiation injury**





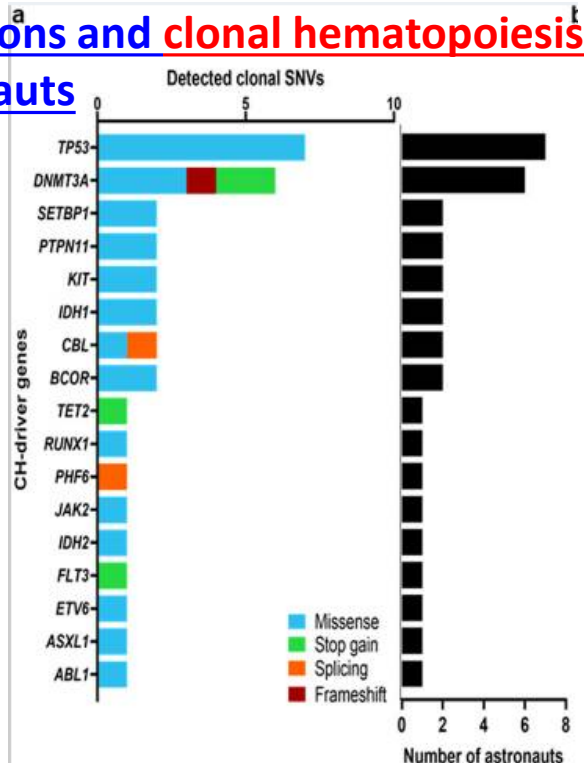
Advantages

- Heart size
- Heart-to-body mass ratio
- Coronary anatomy
- Similar hemodynamics: Heart rate ~50-116 bpm
- Systolic 135-150
- Similar contractile function an
- Slow β-MHC fibers (like humans)
- Excellent model for testing surgical procedures
- Human-like model acute/ chronic ischemia and progression to heart failure
- Same susceptibility to diet-induced hypercholesterolemia
- Myocardial gene delivery-AVVs

Disadvantages

- Some anatomical differences
- High-cost housing
- Grow quite large (e.g., mature Yucatan mini pigs are ~150 lbs-180 lbs)
- Long life span
- Lack of genetic models.

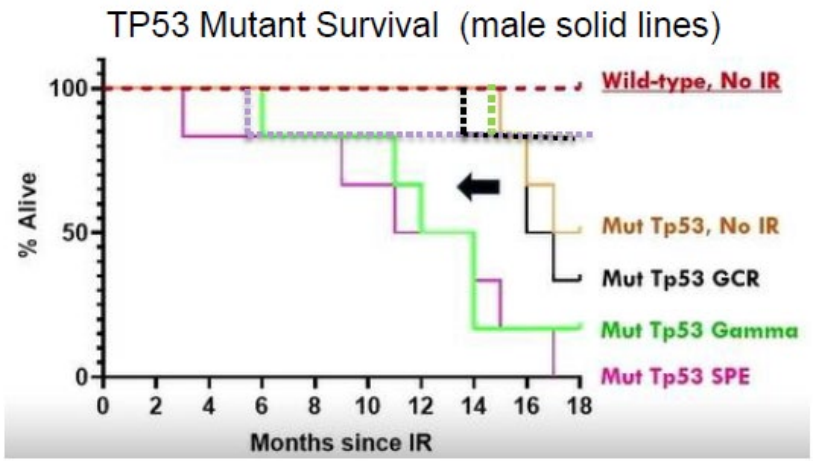
PI: Goukassian – Mount Sinai - Retrospective analysis of somatic mutations and clonal hematopoiesis in astronauts

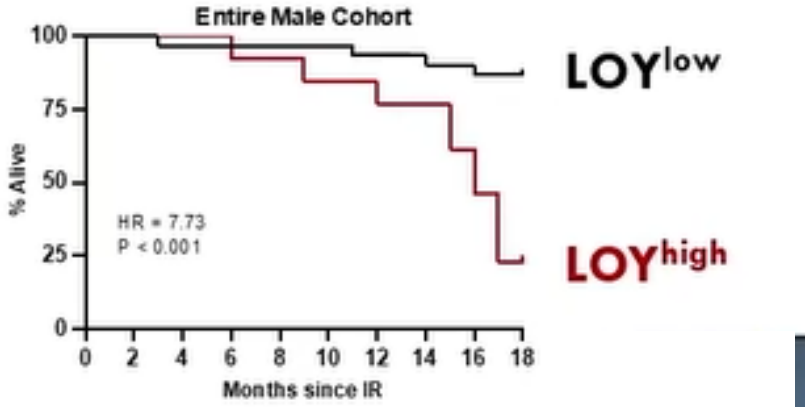


a Mutational profile of 17 known mutated CHIP-driver genes and number of astronauts with mutations in each gene.

Brojakowska A et al.. Aug 17;5(1):828. Commun Biol. 2022 Oct 10;5(1):1078. PMID: 35978153

PI: Kenneth Walsh – Virginia Understanding the Sex-Specific (LOY) Consequences of Ionizing Radiation on Clonal Hematopoiesis

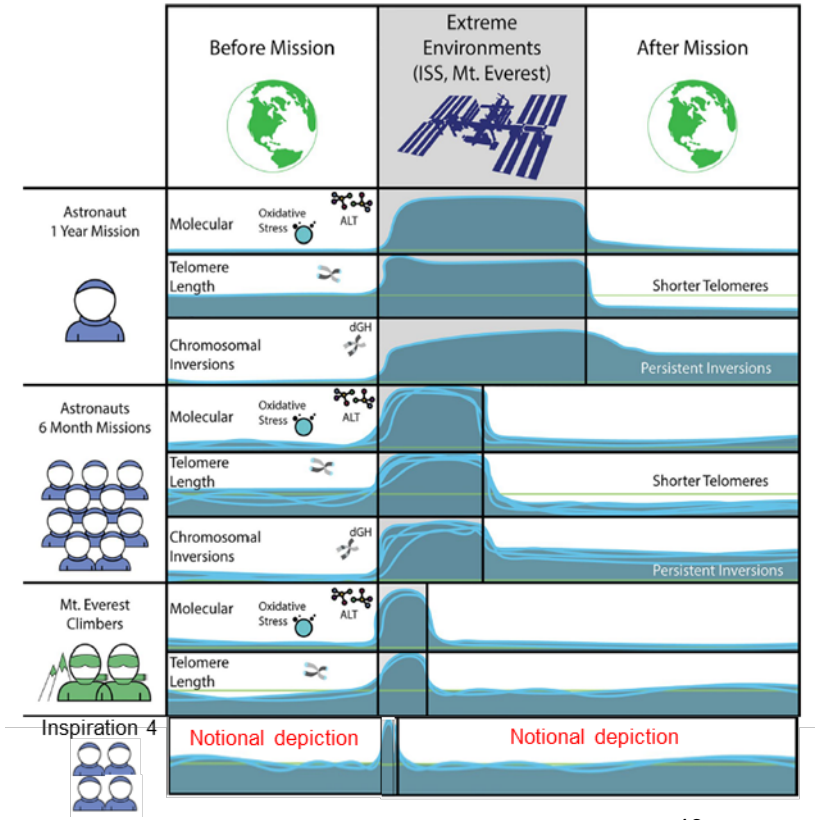




Presented by Kenneth at IWS

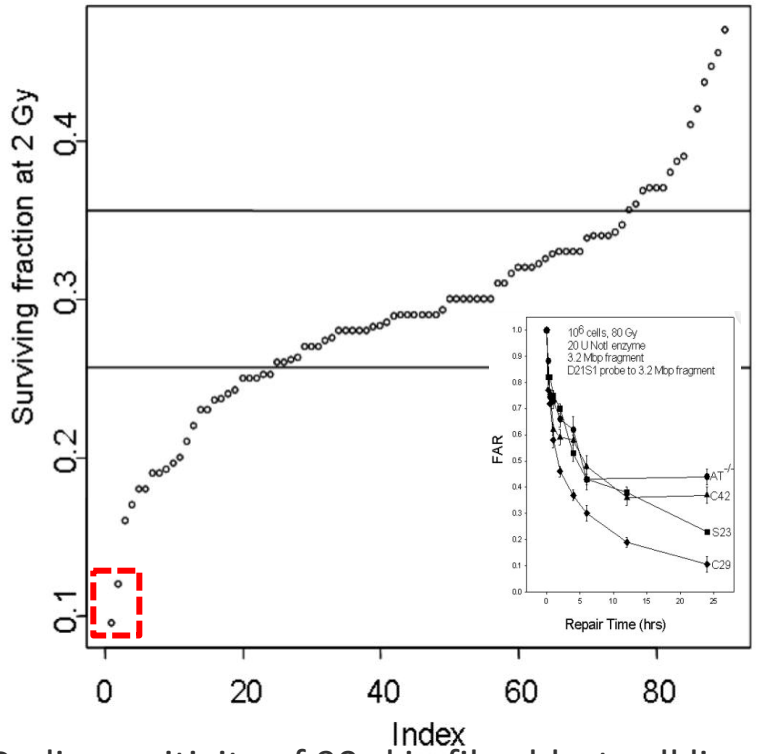
PI: Susan Bailey – CSU - Telomeres and aging: *on and off the planet!*

- **Telomeres seem to lengthen during exposure regardless of type of exposures**
- **Telomeres post-space flight exhibit shortening.**



Mason et al., Biogerontology (2024) 25:313–327 | Al-Turki et al., Communications Biology | (2024) 7:698

PI: Tony Davis – UTSW - Evaluation of the Cellular & Molecular Responses of Lung and Liver Cells Derived From iPSCs With Varying Intrinsic Radiosensitivity to Space Radiation



Radiosensitivity of 90 skin fibroblast cell lines as measured by SF2. Horizontal lines demarcate groups based radiosensitivity: radiosensitive, normal, and radioresistant. Dashed box: Ataxia telangiectasis Cell Line

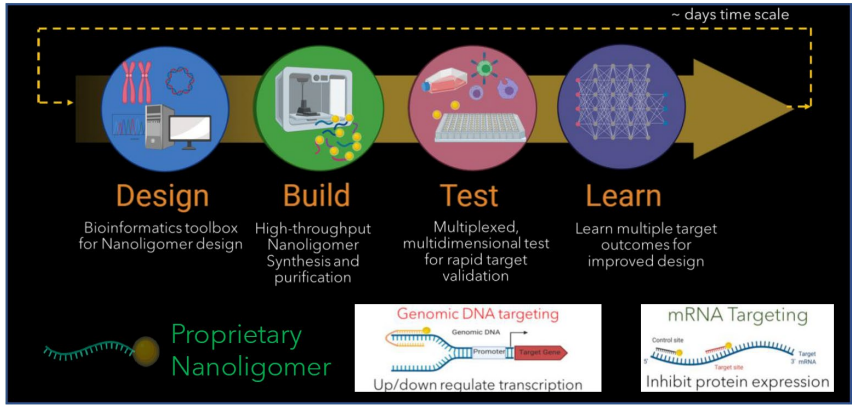
Sachi Bioworks – SBIR Phase 3

1.) Nanoligomer Technology ("3D" Printing drugs)

2.) AI capability to accelerate countermeasure target identification

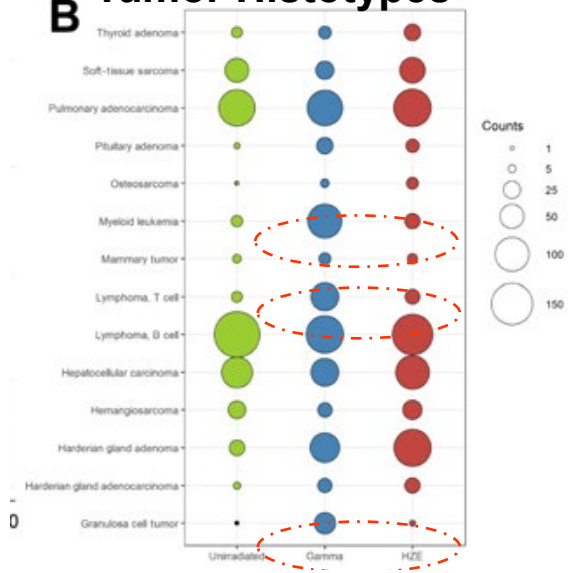
Neuroprotection has been shown:

1. low-dose (0.1 Gy) GCR exposure
2. prion disease model
3. ALS model
4. Alzheimer disease transgenic Model



PI: Mike Weil – CSU - Genomic mapping in outbred mice reveals overlap in genetic susceptibility for HZE ion- and γ-ray-induced tumors

Incidence of Specific Tumor Histotypes



γ HZE

host genetic factors dictate risk for tumor development following radiation exposures, regardless of radiation quality.

Edmondson EF et. Al. PMID: 32494593

Joe Wu - Stanford - Greenstone Bio.

- FDA screen of radiation protectants
- Cardiomyocytes from iPSC
- Xray
  - Validation of results at NSRL

Cell Viability

	1	2	3	4	5	6	7	8	9	10	11	12	Hoechst
A	4441	5183	5911	5120	5734	5243	4817	4970	4839	5125	4973	4424	
B	5971	6404	5244	5407	5545	6234	5520	5255	2837	5768	6116	4443	
C	5904	3614	6502	5962	6476	1470	6425	6404	5941	5894	5568	4260	
D	5057	6526	4638	5260	6599	5673	3176	4900	4598	1035	5040	4193	
E	5391	335	4941	6887	4633	4815	5037	903	3856	4764	5813	4107	
F	4597	5740	4768	4738	4428	4555	4957	4654	4949	5347	5020	4230	
G	1881	1751	2770	6094	5878	4333	4523	4761	5852	3774	723	4138	
H	3084	700	4851	6326	5005	5775	3973	2992	4954	438	4825	4001	

Oxidative Stress

	1	2	3	4	5	6	7	8	9	10	11	12	ROS
A	1485	991	1096	938	1425	1132	1202	1155	1508	1540	1882	1839	
B	2628	2537	1848	1398	1683	2098	1609	1813	1747	2214	1921	1845	
C	2920	1934	2513	2593	2648	1512	2446	3149	2520	2726	3206	2367	
D	2967	3353	2604	1487	3352	1970	2169	2067	2654	23	1567	2299	
E	2843	266	2679	4120	2167	2910	2553	776	2418	2200	2959	2283	
F	2465	3218	2522	3132	1908	5307	2620	2146	2032	3031	2885	2109	
G	1341	772	1750	4969	3320	2624	1891	2628	3072	2716	20	2053	
H	1902	1320	2785	4457	3067	2893	2070	809	2225	385	2565	1999	

Dying/Dead Cells

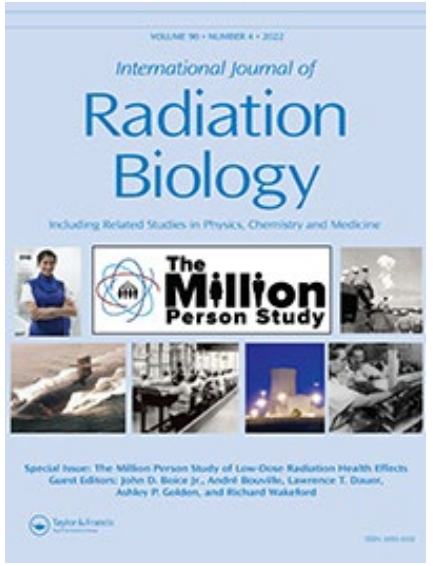
	1	2	3	4	5	6	7	8	9	10	11	12	PI
A	726	647	705	426	626	549	569	519	573	536	558	671	
B	630	663	362	318	461	553	331	423	211	533	454	621	
C	571	400	591	479	566	433	418	456	347	387	431	597	
D	657	499	429	188	580	394	216	293	511	1066	160	555	
E	759	36	445	426	283	297	378	222	498	276	345	460	
F	631	485	487	274	91	236	402	292	401	489	384	472	
G	147	180	422	296	539	538	288	374	586	259	827	633	
H	407	1098	270	399	454	452	329	201	546	67	446	656	

GREENSTONE BIOSCIENCES

National Council Radiation Protection and Measurements (NCRP) (PIs: Boice and Dauer)

Utilizing radiation workers to better characterize the effects of radiation exposure

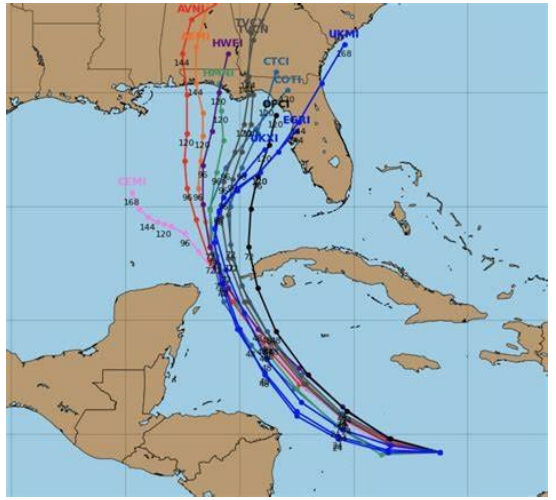
- Million Person Study (MPS)
  - Submariners (radiation, isolation and confinement, Hostile environment)



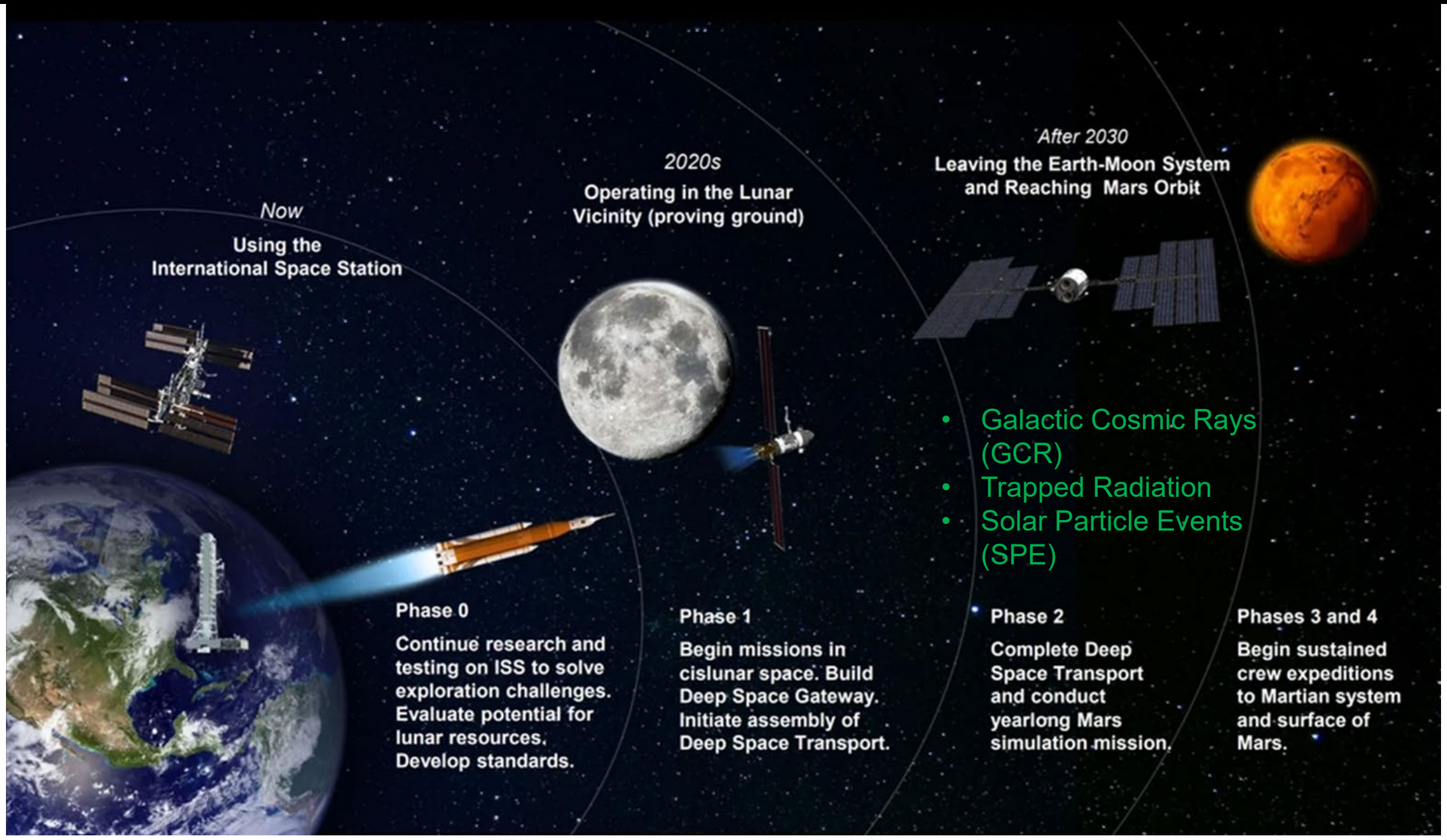
LaRC - Multi-Modal Ensemble Risk Assessment (MERA)

Modeling of Long-Term Health Risk due to radiation exposure

- Cancer (most advanced)
  - incorporating
    - CNS
    - CVD
    - Other risks?



Planned Exploration Activities



- Galactic Cosmic Rays (GCR)
- Trapped Radiation
- Solar Particle Events (SPE)