

NASA HRP Space Radiation Element Status

National Aeronautics and
Space Administration



Janice Zawaski Ph.D., Space Radiation Acting Element Scientist

**NASEM Committee on Biological and Physical Sciences in Space Fall
2023 Meeting**

October 17-19, 2023 Hybrid Meeting



Space Radiation Element

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

Science

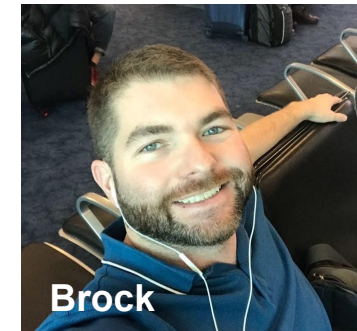
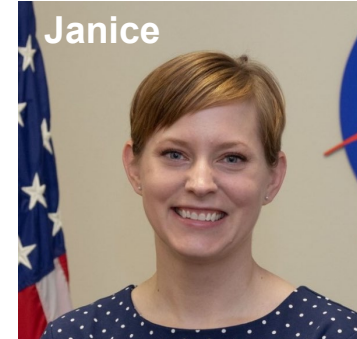
Janice Zawaski Ph.D., “Acting” Element Scientist

Janice Zawaski Ph.D., Deputy Element Scientist

Gregory Nelson Ph.D., CNS Discipline Lead

JP Saha Ph.D., Degenerative Tissues Discipline Lead

Brock Sishc Ph.D., Cancer Discipline Lead



Management

Jason Weeks M.S., Element Manager

Ryan Norman, “Acting” Deputy Element Manager

JordAN Rhone, Science Integrator

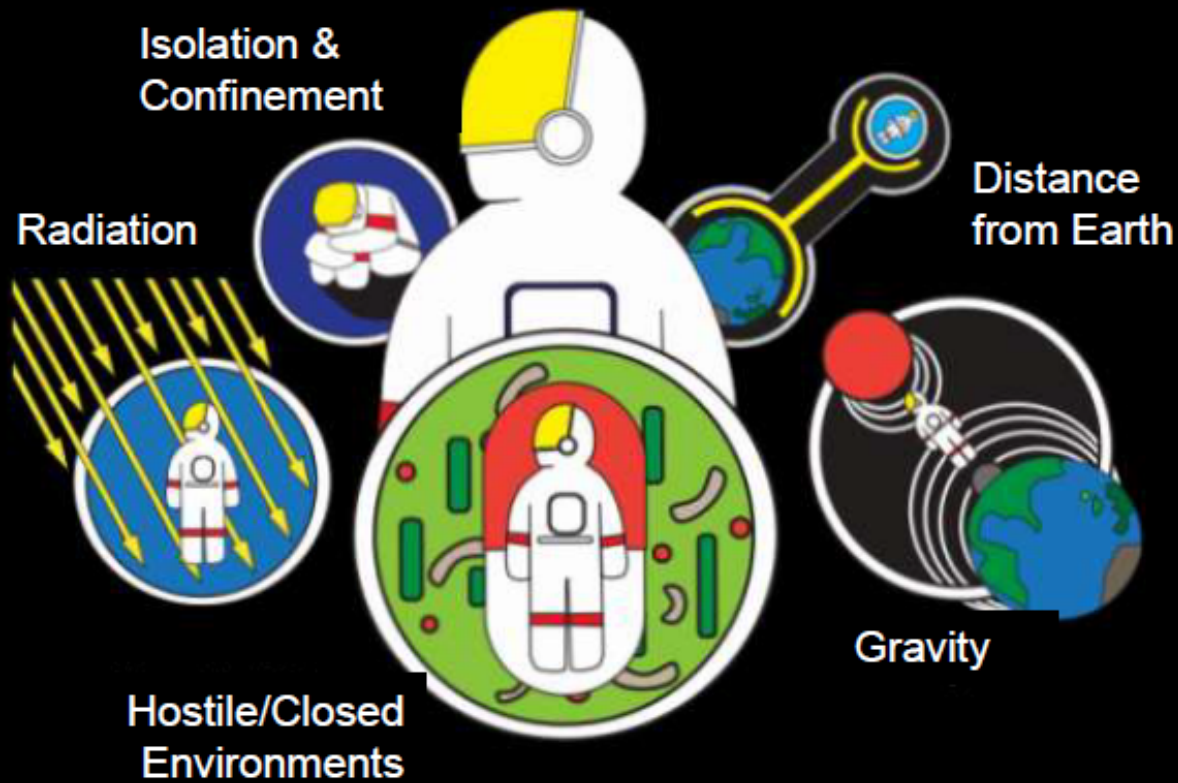


jsc-hrp-space-radiation-element@mail.nasa.gov



Human Research Program

Protect Astronauts' health and performance from five key hazards of spaceflight



...by researching how astronauts' bodies and minds adapt to the extreme environments of space

On Earth

- Ground-based Analogs
- Laboratories
- Simulation & Training

In Space

- ISS
- Gateway
- Moon
- Mars



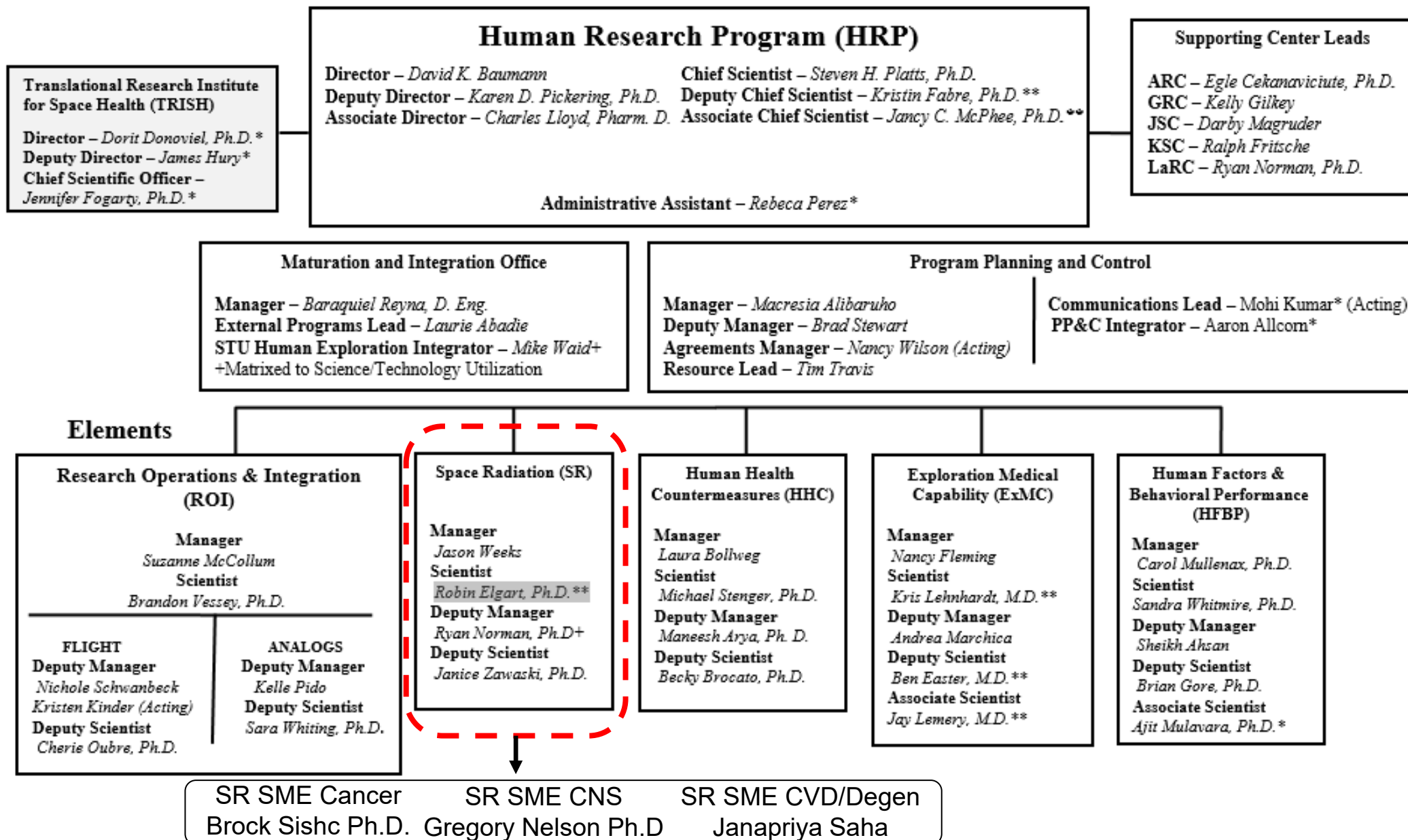
<https://www.nasa.gov/hrp>



NP-2019-03-005-JSC



Human Research Program





Addressing Health Risks



<https://humanresearchroadmap.nasa.gov/>

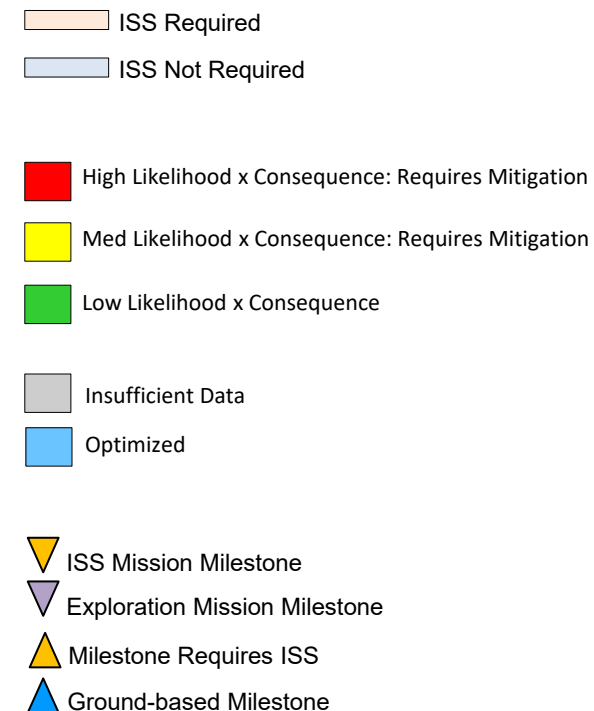
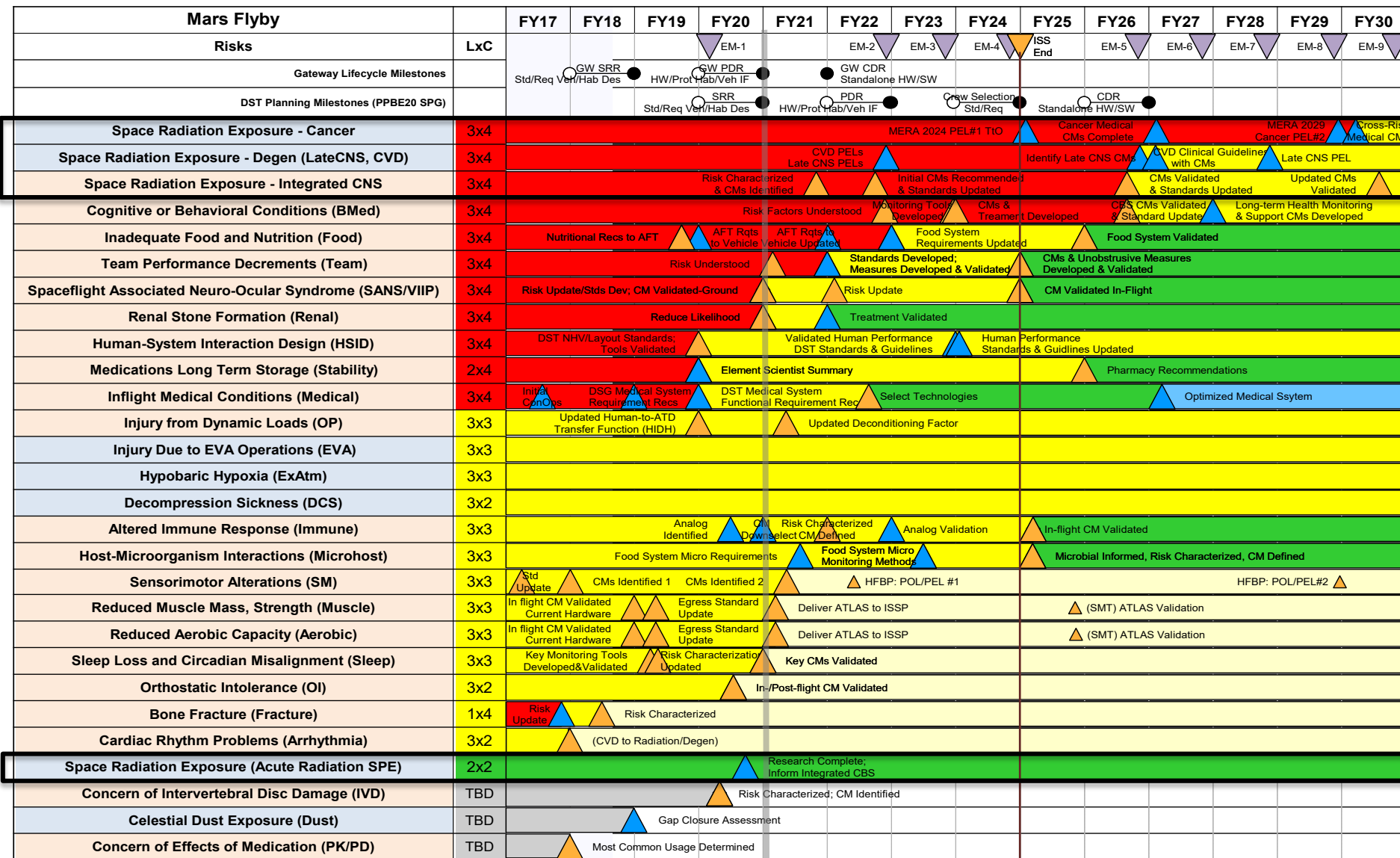


- Five HRP Elements and 23 active risks :
 - Exploration Medical Capability (ExMC)
 - Medical care for deep-space missions
 - Human Factors and Behavioral Performance (HFBP)
 - Interfaces between humans, vehicles, and habitats
 - Individual and interpersonal
 - Human Health Countermeasures (HHC)
 - Physiology
 - **Space Radiation (SR)**
 - **Biological effects of radiation exposure**
 - Research Operations and Integration (ROI)
 - Infrastructure for flight and analog experiments
- Funds Translational Research Institute for Space Health (TRISH) to pursue disruptive, breakthrough approaches that reduce risks to human health and performance
- Collaborates with NASA Space Biology program to understand causal cellular and other mechanisms that underlie adaptation to spaceflight in cells, microorganisms, plants, and animals





HRP Integrated Path to Risk Reduction



ISS End

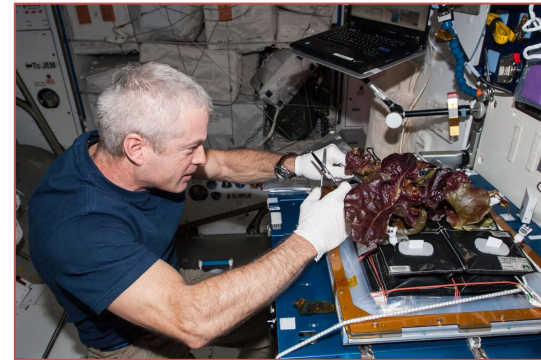
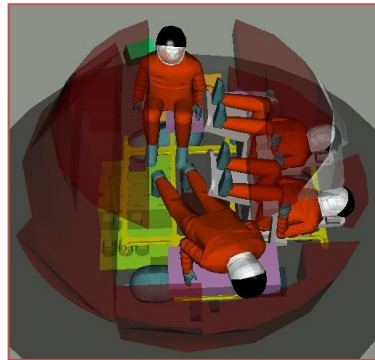
PPBE20 Baseline
HRPCB-approved
27 June 2018



An **Applied** Research Program

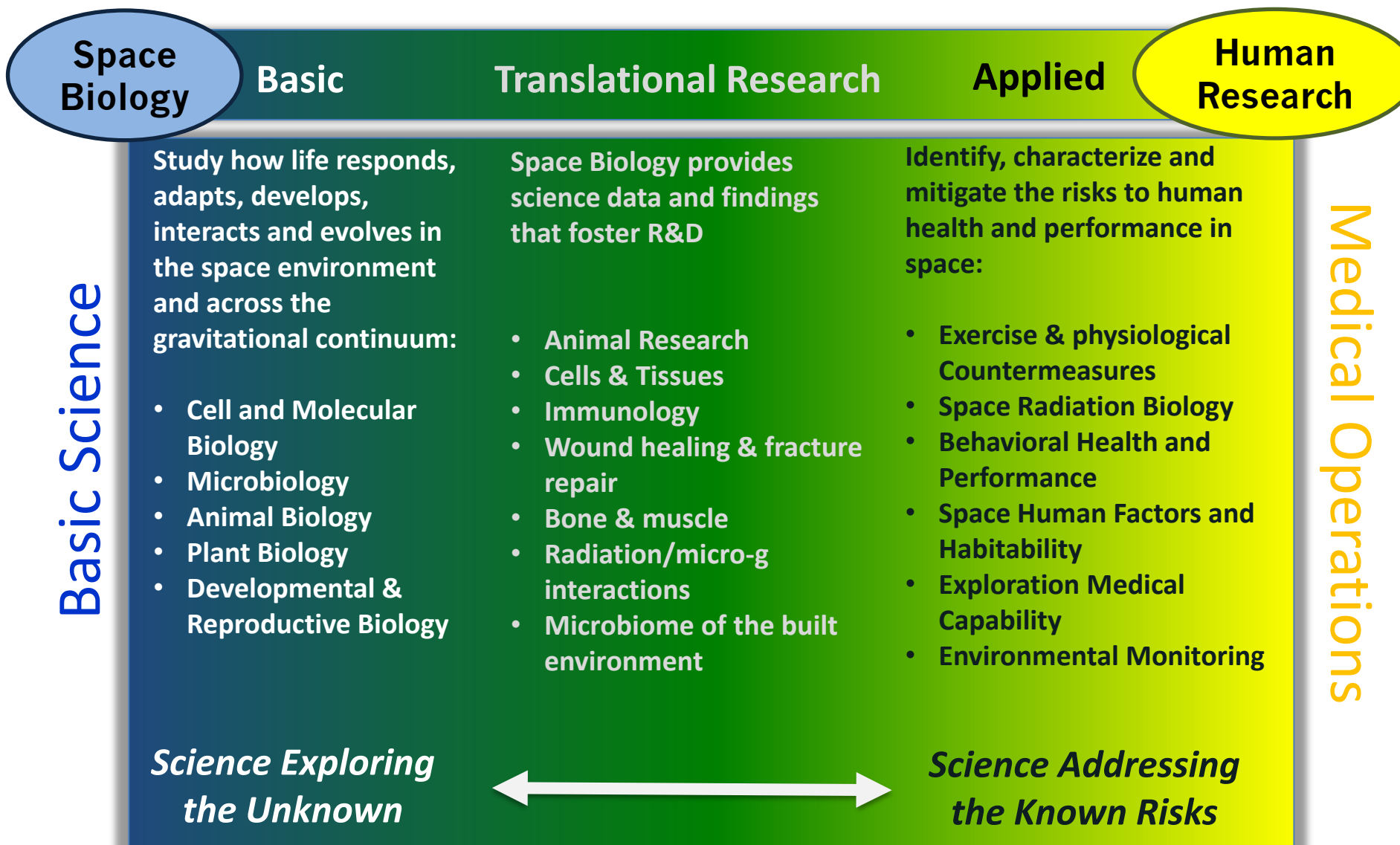
- **Scientific Goals**

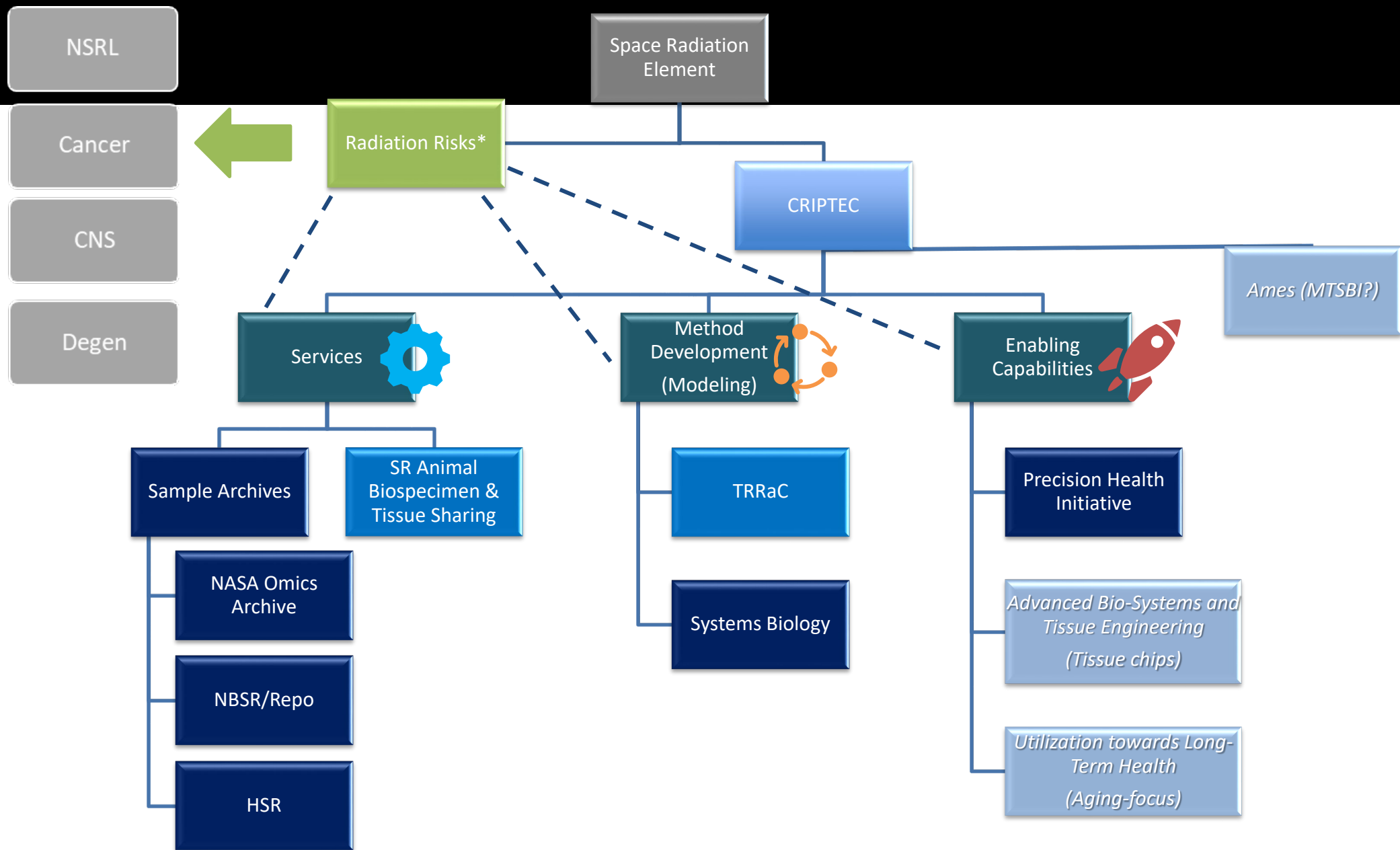
- Understand and mitigate human health and performance risks due to the five known hazards of spaceflight
- Enable development of human spaceflight medical and human performance standards
- **Develop and validate technologies that serve to characterize and reduce health risks associated with human spaceflight**





Translating Basic Science to Applications (Example in Biomedicine)



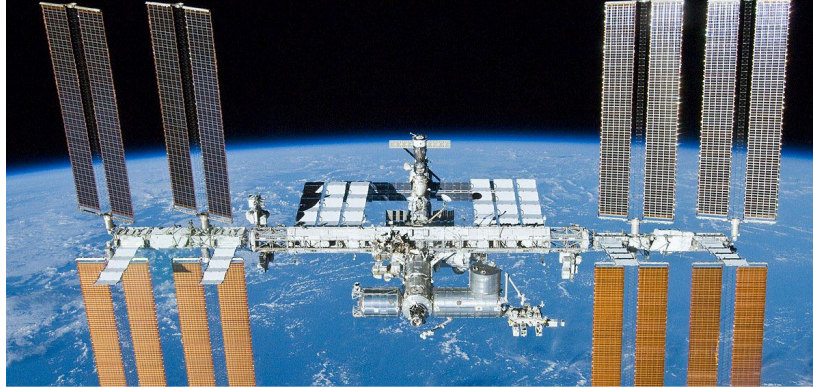


Dark blue boxes indicate cross cutting projects new to SR Element
 Light blue boxes indicate future projects

*All CRIPTEC focus areas can be leveraged to support other Element Risks



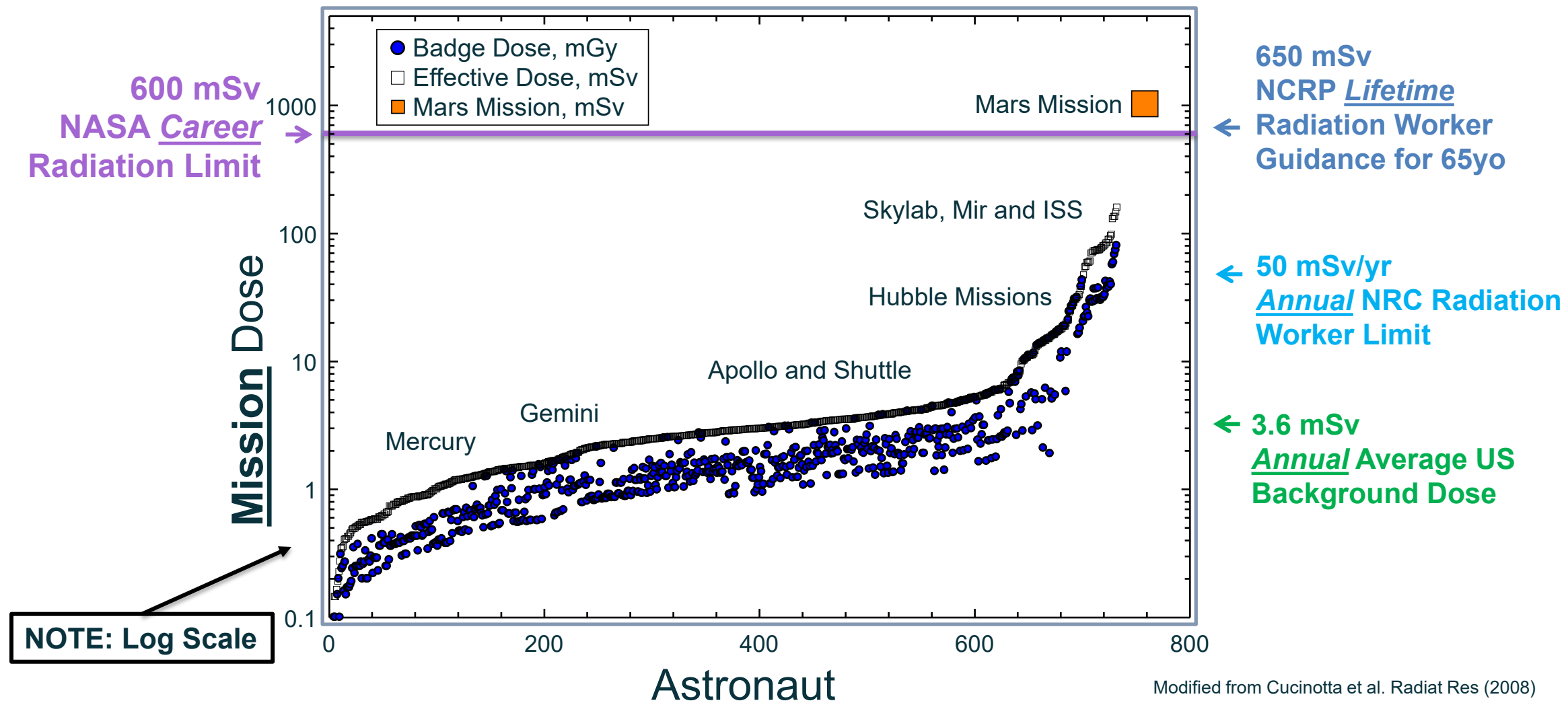
What's Out There? The Space Radiation Environment



Exposure Type	ISS (51.6° inclination)	Beyond Leo Earth Orbit
Galactic Cosmic Rays (GCR)	• Limited to polar regions • <u>Fractionated</u> low dose-rate • ~ 87% protons, 12% Helium, 1% HZE	• Continuous • <u>Chronic</u> 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 • <u>Chronic</u> low dose-rate	• Shielding • Planetary (albedo) • <u>Chronic</u> low dose-rate



Historical NASA Crew Mission Doses





Mission Success

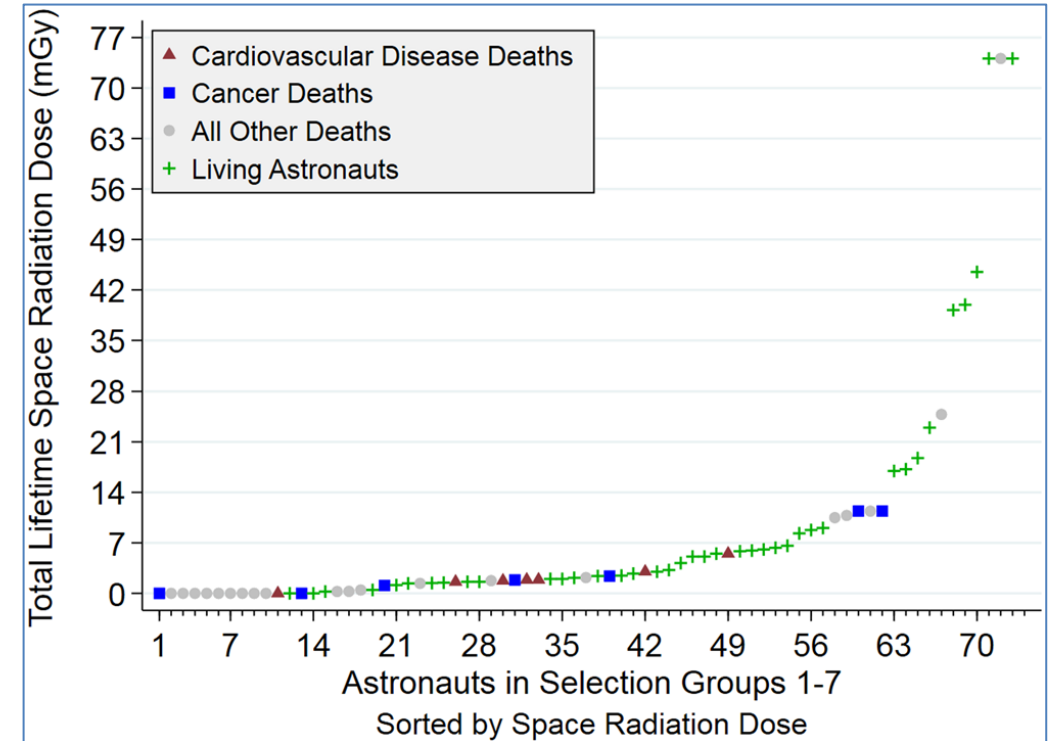
- Acute effects
 - Very large high-energy solar events
 - Estimate ~ 200 – 400 mSv (unsheltered) for 1972 Event
 - **MILD** symptoms IF they occur at all given doses
- Potential early neurological effects
 - Behavior or memory decrements
 - Observed only in animal models

Long Term Health

- Cancer
 - Space radiation may cause unique impacts
- Degenerative
 - Cardiovascular disease
 - Cataracts
 - Immune
- Potential late neurological decrements
 - Behavior or memory decrements
 - Neurodegenerative disease
 - Observed only in animal models

- **Limited observed outcomes in astronauts**

- Small population
- Low doses and dose rates
- Common outcomes
- Healthy worker and generally healthy

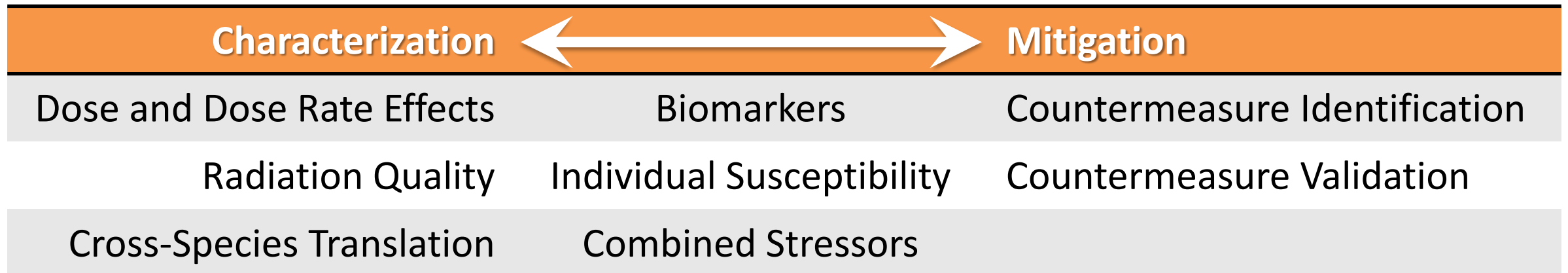


- **Limited knowledge of biological effects of space radiation**
 - Heavy reliance on animal studies
 - Space radiation is unique



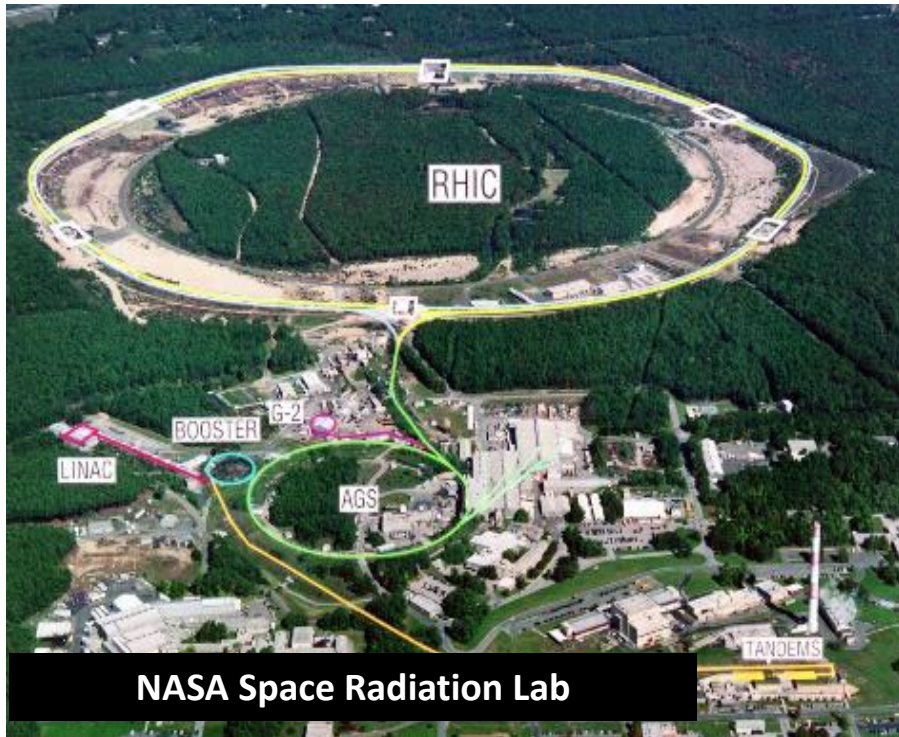
Space Radiation Element Research

- **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**





Ground Analog – NASA Space Radiation Laboratory



Personnel:

NSRL liaison physicist, Dr. Adam Rusek (rusek@bnl.gov)

Biology support scientist, Dr. Peter Guida (guida@bnl.gov)

NSRL Management, Lisa Simonsen Ph.D.

Capabilities:

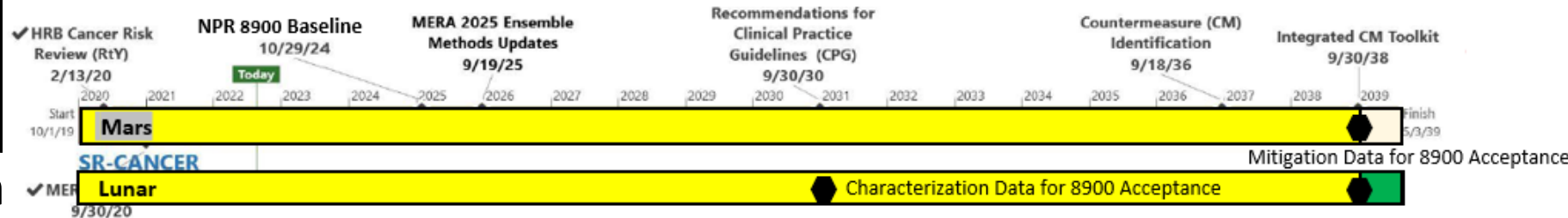
- Acute or fractionated exposures “chronic”
- Single ions
- Multiple ions
 - Simplified GCR sim [6 beams 5 ions: H (2 energies), Si, He, O, & Fe]
 - GCR sim [33 beams, 7 ions: H (14 energies), He (14 energies), C, O, Si, Ti, & Fe]

Budgeting:

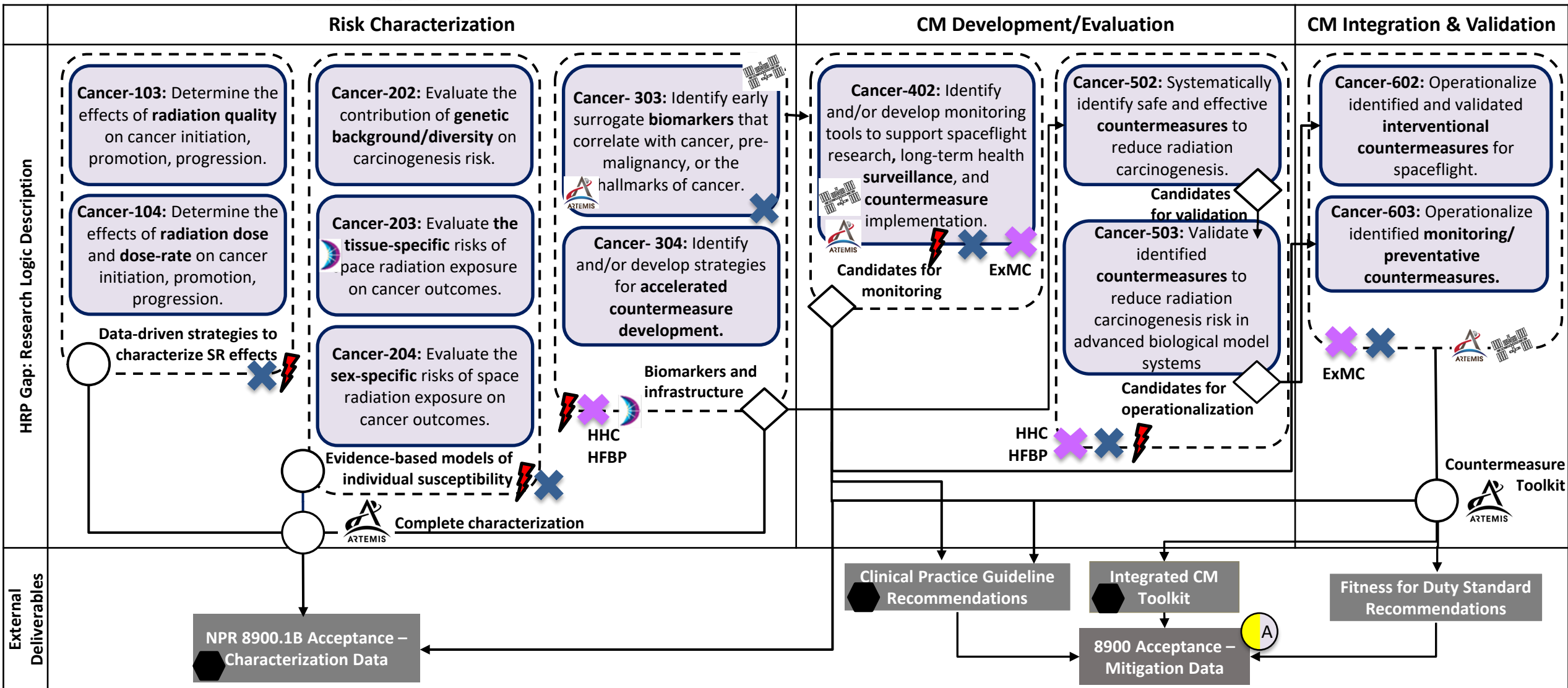
- Beam time is covered if funded by the Space Radiation Element
- Animal Housing costs (acclimation and during irradiation)
- Personnel travel/housing/per diem costs (onsite personnel is need during experiment)

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

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

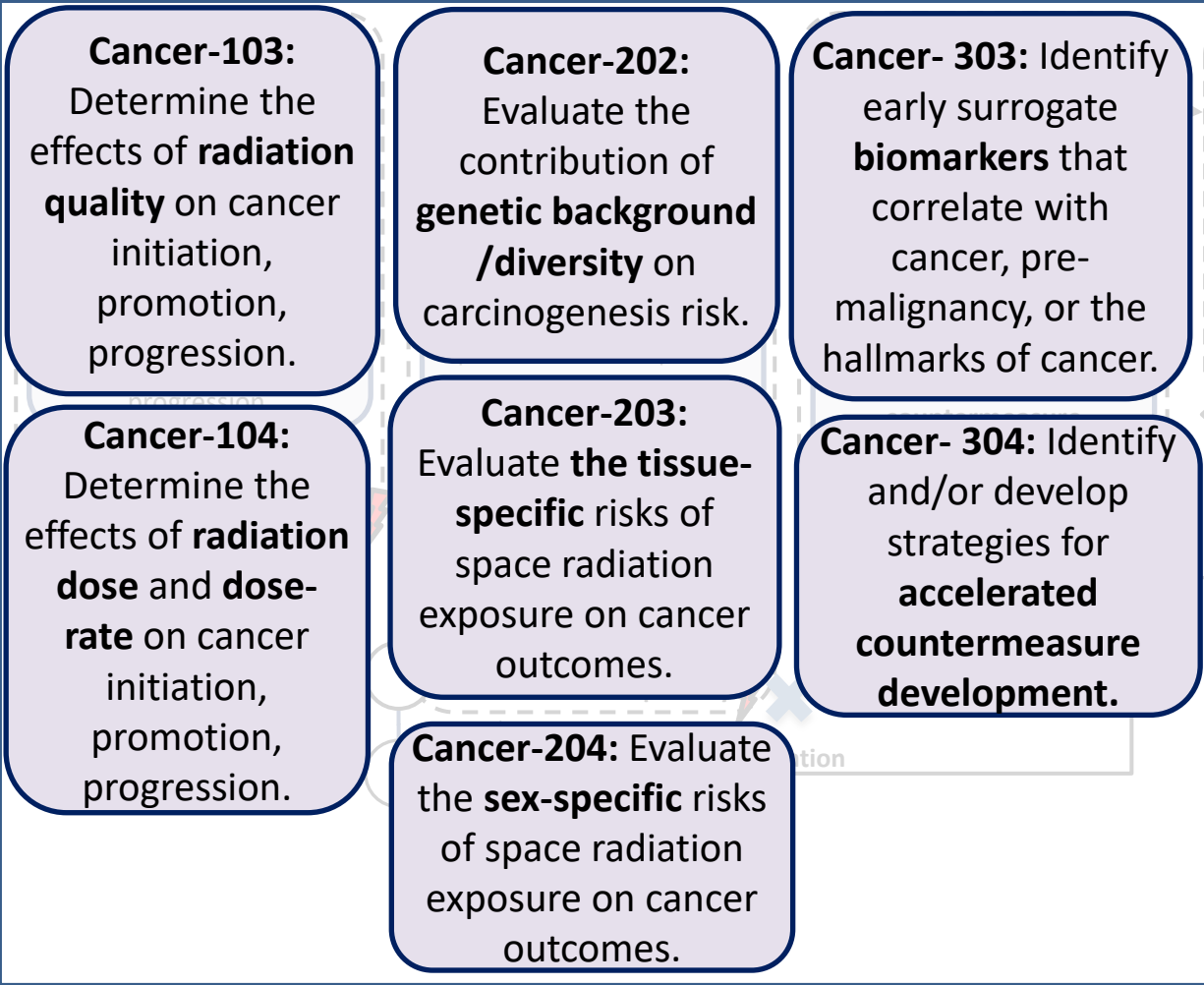


Approach Plan



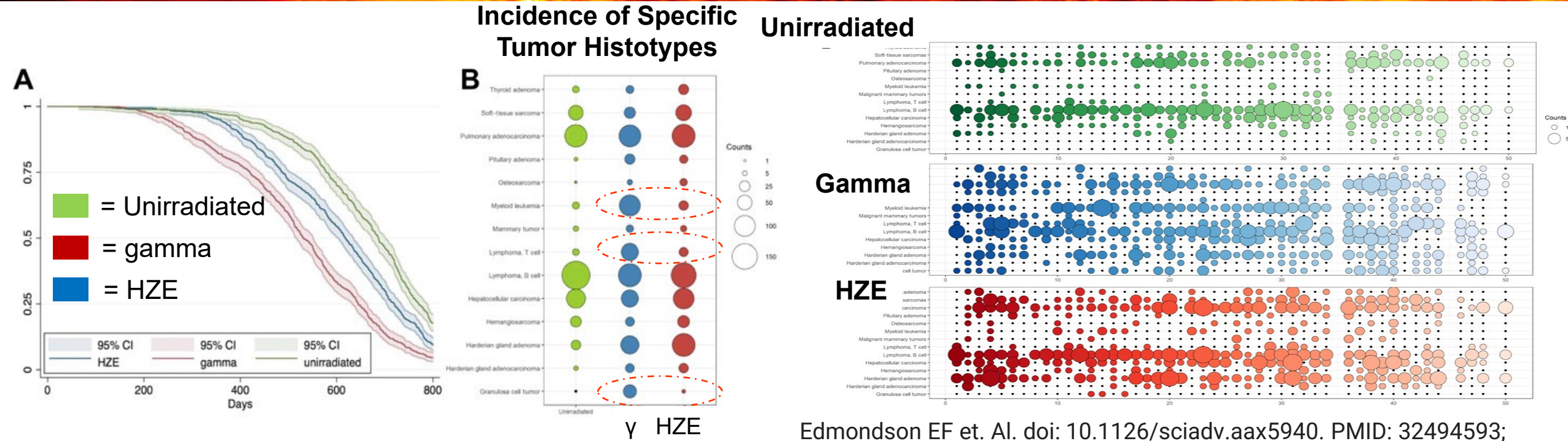


Adapting to Space: KSQ



1. How does the space environment influence biological mechanisms required for organisms to survive the transitions to and from space, and thrive while off Earth?
2. Do genetic diversity and life history influence physiological adaptation to the space environment?
3. How does the space environment alter interactions between organisms?

Radiation Quality Directed Study



Main Take aways from a genetically diverse population:

- the spectrum of tumor histotypes observed in particle radiation exposed mice is not unique to that observed in a population exposed to photon radiation or to the tumor spectrum observed in an unirradiated population.
- Many tumor histotypes show high incidences within some families but are absent or rare in others which is consistent with genetic susceptibility to certain tumor types.**
- host genetic factors dictate risk for tumor development following radiation exposures, regardless of radiation quality.
- Risk for cataractogenesis was associated with family structure (<https://doi.org/10.1016/j.lssr.2023.09.004>)
- revealed an overlap between individual susceptibility to both cancer and cataract.



Radiation Quality Directed Study



Future work will utilize the outbred model in previous slide to inform:

- RQ and RBE estimates
 - **Targeted closure of Gap 103** concerning radiation quality
- Contribution of background/diversity on risk (Gap 202)
- Sex difference (Gap 204)
- Understanding regarding tissue specific risk (Gap 203)

Other Risk Opportunities:

- **CNS functional non-invasive measurements**
- **CVD functional non-invasive measurements**
- **Tissue sharing for all risks (post-morbidity/end point)**
- Potential to add a countermeasure are if something is identified in the next ~3 years



Potential to feed into Adapting to Space Theme (KSQ 1-3)

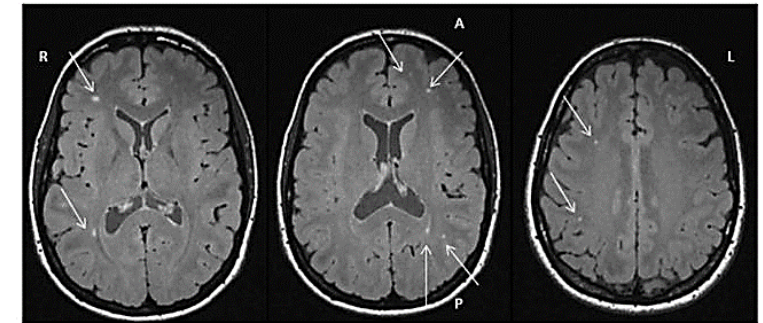
- Potential SR- BPS Collaboration



Mini-Pig: USAF 29-A Experiment



- **Have collected and will assess minipig tissues for short-term impacts via MOU with USAF**
 - Seve as a ***pilot*** for future collaborative minipig work
 - Understand working relationship
 - Optimize tissue collection, processing, and analysis
 - Preliminary data for planned upcoming work
 - 24 Male Yucatan Minipigs
 - Tissues: Brain, Eyes, Heart, Lungs, Kidneys, Liver, Skull Cap, Femur, Bone Marrow, Lymph Nodes, Buccal Swab, Blood/plasma
 - Cohort II scheduled for winter/spring (2024)
- **Augmenting multiple HRP grants to take advantage of the opportunity**
 - miRNA signatures from spaceflight
 - Ocular vasculature and changes in retina
 - Impacts to bones
 - Omics similar to what we plan to do with NASA Omics Archive
 - Remaining tissues will be made available for tissue sharing
 - [**KSQ 1-2, Collaboration Point?**](#)



McGuire et al. Hyperintense white matter lesions in 50 high-altitude pilots with neurologic decompression sickness. *Aviat Space Environ Med.* 2012; 82(12):1117-1122.



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

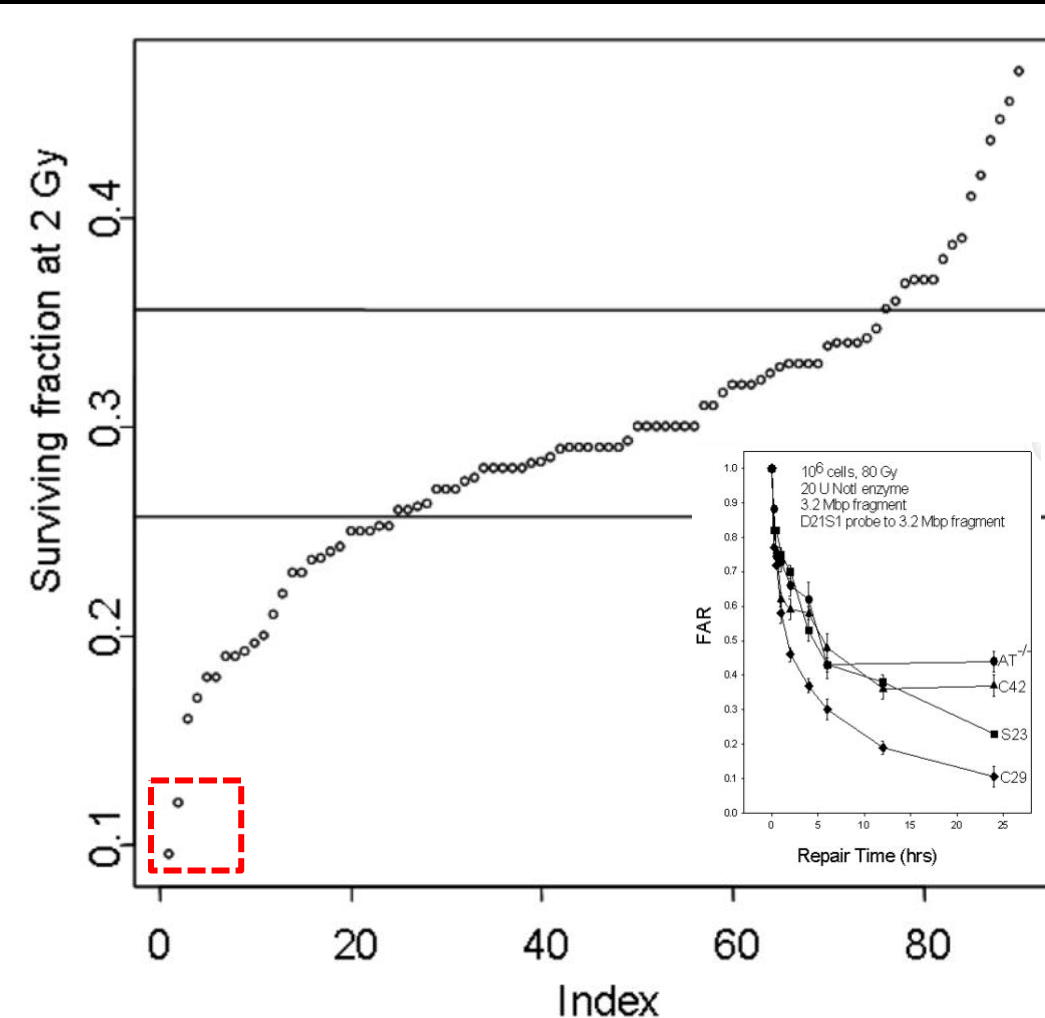
PI: Anthony “Tony” Davis / UTSW

PHSFs will be utilized to generate immortalized PHSFs and 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,

- 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. (KSQ-2)



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



Previous Funding:

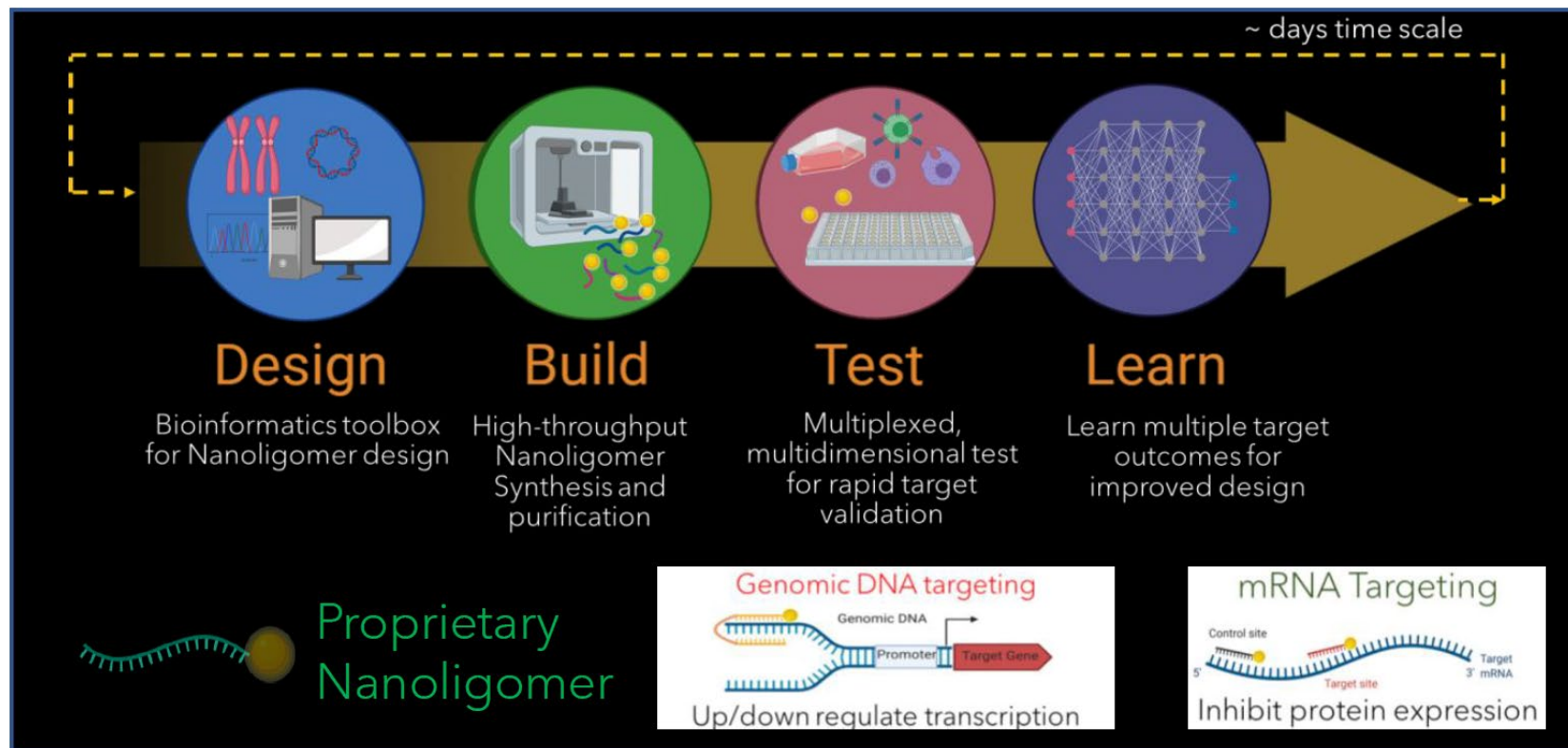
- TRISH
- SBIR Phase I
- SBIR Phase II

Evaluation of SBIR Phase IIE underway

- 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



Recommendation 4-2: How cells, systems, and organisms concurrently adapt to the spaceflight environment and develop mechanisms for encouraging positive and countering negative communicated responses. (Page 100)

KSQ-3



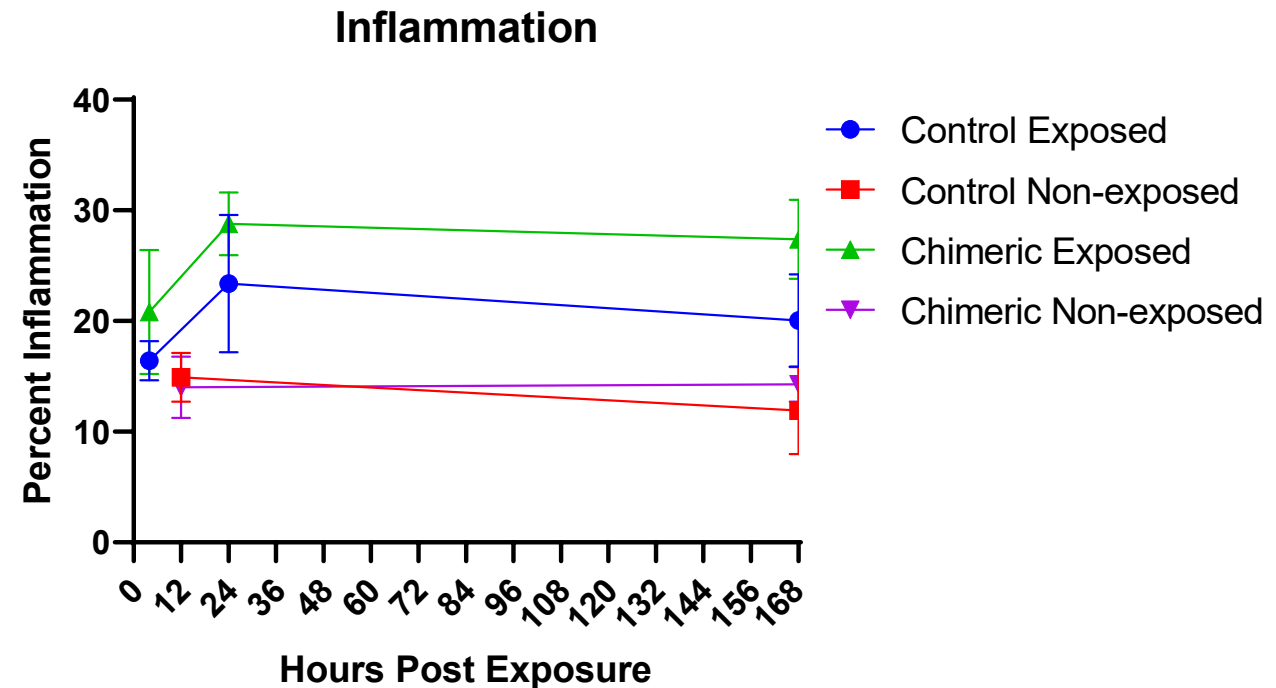
Chimeric Mouse Models for Space Radiation Risk Investigations

PI: Honglu Wu

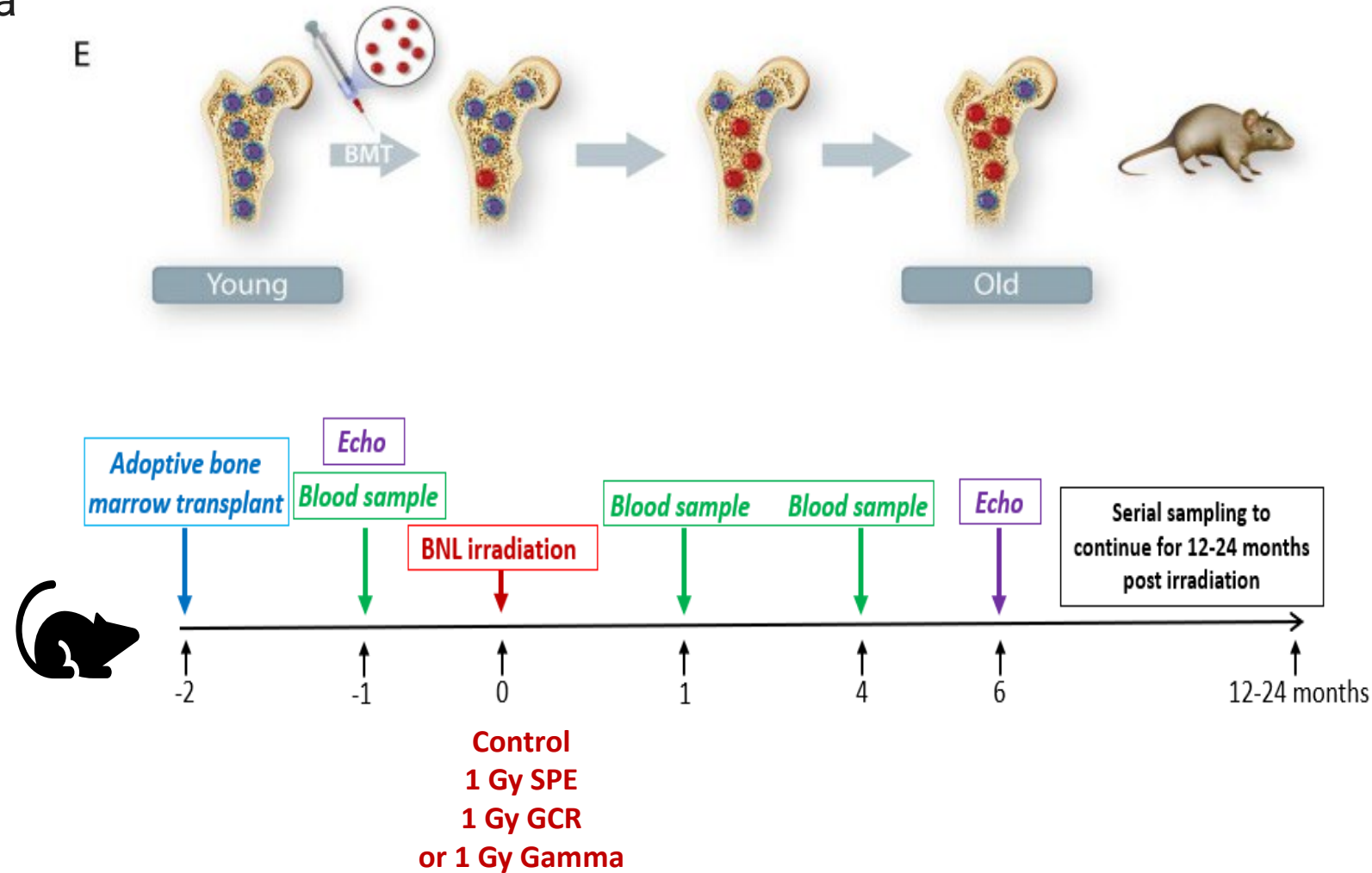
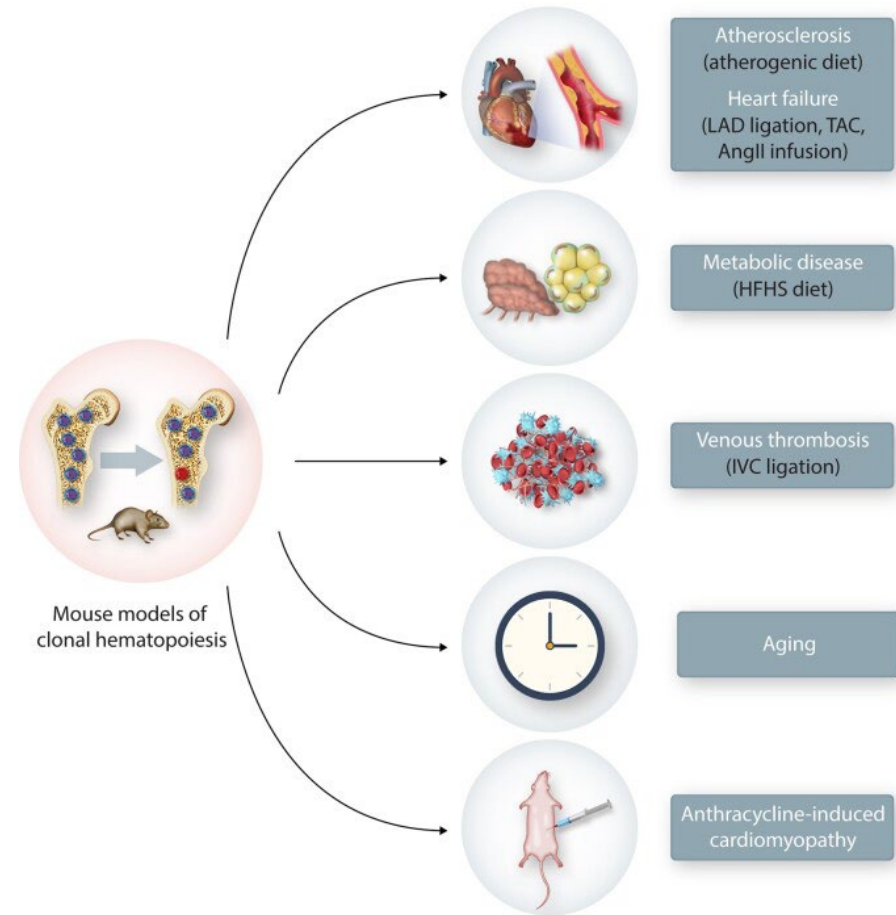
- **Expand translational research = preclinical animal models of astronaut health hazards**
 - Risk assessment
 - Countermeasure development
 - Mitigation planning
- **Mouse models = multiorgan mammalian test system**
 - Mouse $\neq$ Human $\rightarrow$ Chimeric/humanized mice
 - PhoenixBio PXB Mouse = human livers in mouse model system
- **PXB mice and controls exposed to radiation**
 - Controls = genetic background of PXB, Fox Chase SCID
 - Liver tissue analyzed with histopathology and RNA analysis

KSQ: 1-3

Group	Treatment
12 hr control 7 day control	Restraint only
4 hr exposed 24 hr exposed 7 day exposed	2 Gy Exposure



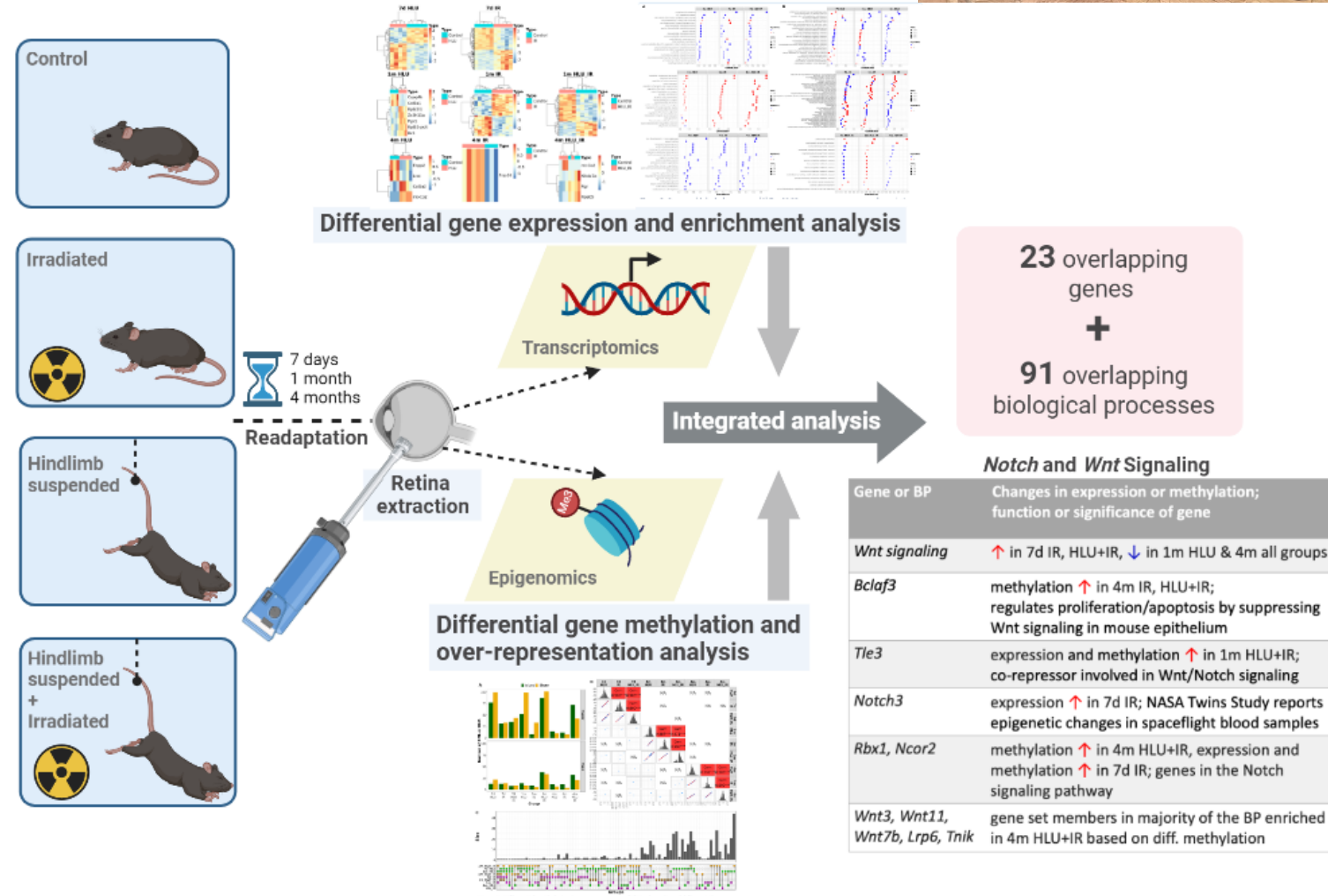
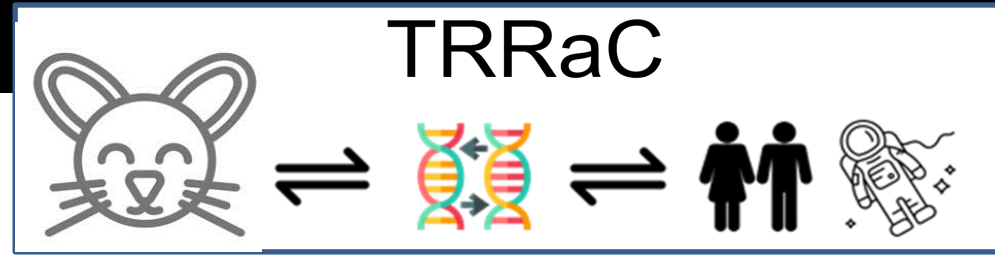
PI: Kenneth Walsh, University of Virginia





TRRaC

- ❖ Developing and establishing cloud-based data transfer architecture and pipeline development
- ❖ Collaborated with three external PIs on the in vivo data
- Published findings on longitudinal effects of space radiation and microgravity on murine retina in Scientific Report Journal. DOI: [10.1038/s41598-022-19360-9](https://doi.org/10.1038/s41598-022-19360-9)
 - Open-source code available for the pipe-line developed for the retina paper tinyurl.com/ykn6889e
- Developed methods to harmonize and curate omics related data for machine learning analysis (methods to be published) on 6 different space-flight liver studies.





CIPHER (Complement of Integrated Protocols for Human Exploration Research)



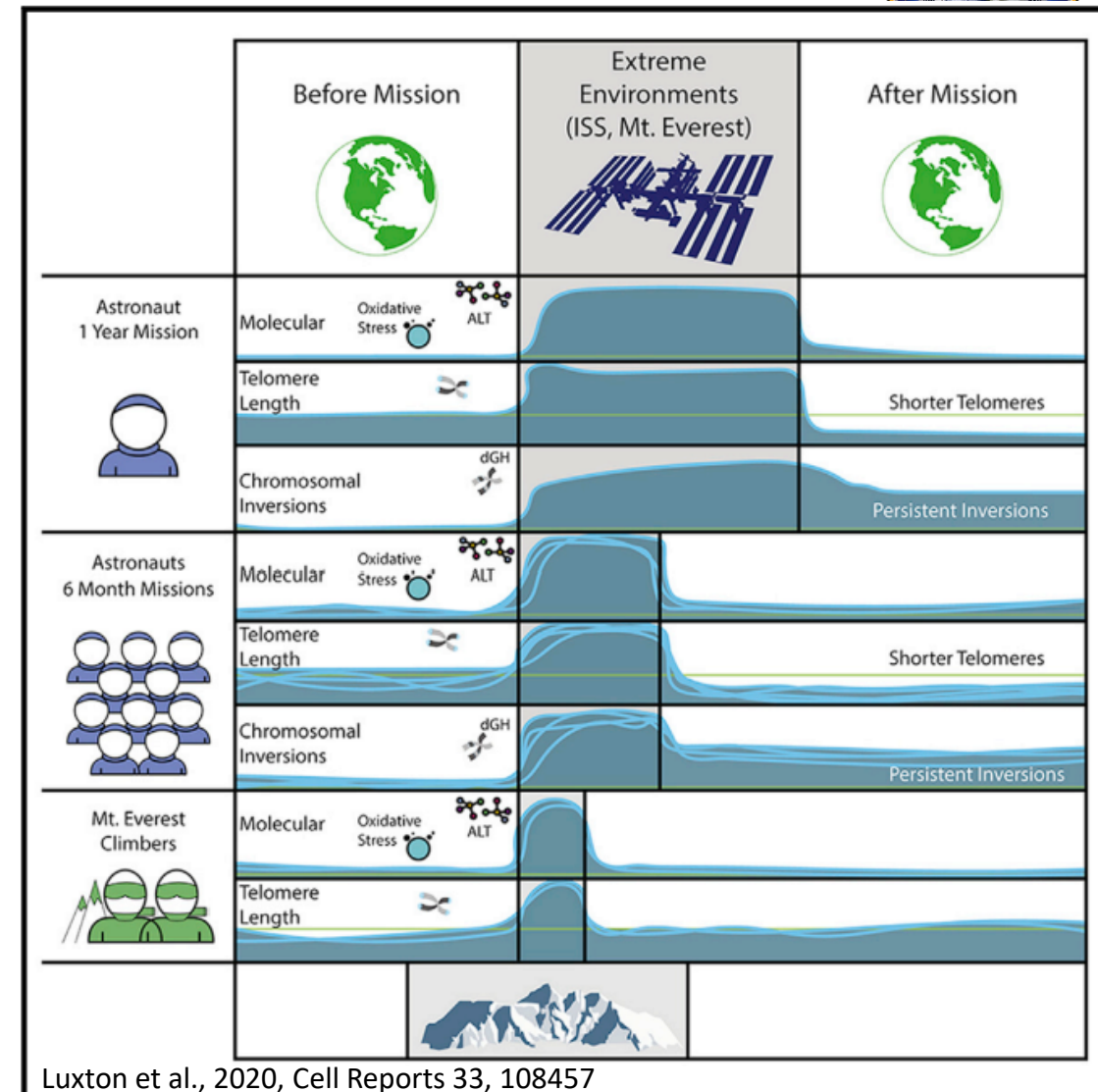
BIOMARKERS

Astronauts will:

- Provide blood and urine samples before, during, and after spaceflight, and
- Complete questionnaires regarding health and exercise habits.

Scientists will:

- Examine blood and urine for potential indicators of changes to cartilage health, inflammation and immune function, kidney health, brain structure and function, spatial cognition, performance of operational tasks, risk of cardiovascular disease, and more; and
- Investigate the interplay between mission length, DNA damage responses, and post-mission recovery of telomeres – the caps at the ends of chromosomes that shorten as we age but may lengthen in space before rebalancing themselves back on Earth. (PI: Susan Bailey)



- Other measurements: cardiovascular, bone & joint health, Exercise, Sensorimotor, vision



- **Objective – Establish a comprehensive, longitudinal molecular dataset from astronaut participants engaged in space flight missions for the purpose of identifying the molecular, metabolic, and microbiome changes associated with long duration space flight missions.**

Example Proposed 6 Month Mission Duration

Sample Type	Analysis	Pre-flight	In-flight	Post-flight
Buccal swabs	DNA sequencing* Epigenetics	L-90	FD30, FD120, R-30	R+0, R+30
Blood, Serum	Proteomics	L-180, L-60	FD30, FD120, R-30	R+0, R+30
Blood, Plasma	Metabolomics	L-180, L-60	FD30, FD120, R-30	R+0, R+30
Blood, PAXgene	RNA sequencing	L-180, L-60	FD30, FD120, R-30	R+0, R+30
24-hour Urine	Metabolomics	L-180, L-60	FD30, FD120, R-30	R+0, R+30
Body, fecal swabs, saliva	Microbiome	L-90	FD30, FD120, R-30	R+30



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 Thel², Eunbee Park²
Malik Bissier¹, Venkata Naga Srikanth Garikipati³, Lahouaria Hadri¹, Paul J. Mills⁴
Kenneth Walsh² & David A. Goukassian¹✉

With planned deep space and commercial spaceflights, gaps remain to address health risks in astronauts. Multiple studies have shown associations between clonal expansion of hematopoietic cells with hematopoietic malignancies and cardiometabolic disease. This expansion of clones in the absence of overt hematopoietic disorders is termed clonal hematopoiesis (CH) of indeterminate potential (CHIP). Using deep, error-corrected, targeted DNA sequencing we assayed for somatic mutations in CH-driver genes in peripheral blood mononuclear cells isolated from de-identified blood samples collected from 14 astronauts who flew Shuttle missions between 1998–2001. We identified 34 nonsynonymous mutations of relatively low variant allele fraction in 17 CH-driver genes, with the most prevalent mutations in *TP53* and *DNMT3A*. The presence of these small clones in the blood of relatively young astronaut cohort warrants further retrospective and prospective investigation of their clinical relevance and potential application in monitoring astronaut's health.



Review

High-LET-Radiation-Induced Persistent DNA Damage Response Signaling and Gastrointestinal Cancer Development

Kamendra Kumar ¹ , Santosh Kumar ¹, Kamal Datta ^{1,2}, Albert J. Fornace, Jr. ^{1,2}  and Shubhankar Suman ^{1,2,*}

¹ Department of Oncology, Lombardi Comprehensive Cancer Center, Georgetown University Medical Center, Washington, DC 20057, USA; kk1264@georgetown.edu (K.K.)

² Department of Biochemistry and Molecular & Cellular Biology and Department of Oncology, Georgetown University Medical Center, Washington, DC 20057, USA

* Correspondence: ss2286@georgetown.edu; Tel.: +1-202-687-3104

Abstract: Ionizing radiation (IR) dose, dose rate, and linear energy transfer (LET) determine cellular DNA damage quality and quantity. High-LET heavy ions are prevalent in the deep space environment and can deposit a much greater fraction of total energy in a shorter distance within a cell, causing



RESEARCH ARTICLE

Heavy-ion radiation-induced colitis and colorectal carcinogenesis in $Il10^{-/-}$ mice display co-activation of β -catenin and NF- κ B signaling

Shubhankar Suman^{1*}, Bo-Hyun Moon¹, Kamal Datta^{1,2}, Bhaskar V. S. Kallakury³, Albert J. Fornace, Jr.^{1,2}

1 Department of Oncology and Lombardi Comprehensive Cancer Center, Georgetown University Medical Center, Washington, DC, United States of America, **2** Department of Biochemistry and Molecular & Cellular Biology, Georgetown University Medical Center, Washington, DC, United States of America, **3** Department of Pathology, Georgetown University Medical Center, Washington, DC, United States of America

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Abstract

Space radiation-induced gastrointestinal (GI) cancer risk models for future interplanetary astronauts are being developed that primarily rely on quantitative animal model studies to assess radiation-quality effects of heavy-ion space radiation exposure in relation to γ -rays. While current GI-cancer risk estimation efforts are focused on sporadic GI-cancer mouse



OPEN ACCESS

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Fareh F, Zuloaga DG, Marzulla T,
Stewart B, Rosi S, Turker MS and Raber J
(2023), Postsynaptic density radiation
signature following space irradiation

Postsynaptic density radiation signature following space irradiation

Soren Impey^{1,2*}, Carl Pelz¹, Lara-Kirstie Riparip³,
Amanuel Tafessu¹, Fatema Fareh¹, Damian G. Zuloaga⁴,
Tessa Marzulla⁴, Blair Stewart⁴, Susanna Rosi³, Mitchell S. Turker⁵
and Jacob Raber^{4,6*}

¹Department of Pediatrics, Oregon Stem Cell Center, Oregon Health and Science University, Portland, OR, United States, ²Dow Neuroscience Laboratories, Department of Cell and Developmental Biology, Legacy Research Institute, Legacy Health Systems, Oregon Health and Science University, Portland, OR, United States, ³Departments of Neurological Surgery and Physical Therapy and Rehabilitation Science, Brain and Spinal Injury Center, University of California, San Francisco, San Francisco, CA, United States, ⁴Department of Behavioral Neuroscience, Oregon Health and Science University, Portland, OR, United States, ⁵Department of Molecular and Medical Genetics, Oregon Institute of Occupational Health Sciences, Oregon Health and Science University, Portland, OR, United States, ⁶Departments of Neurology and Radiation Medicine, Division of Neuroscience ONPRC, Oregon Health and Science University, Portland, OR, United States



Other Work of Interest



- **Dr. Fornace:** Space Radiation-Induced Persistent Estrogenic Response and Risk of Breast Cancer Development
 - mRNA expression analysis from γ - and GCR-exposed mice breast tissue showed a significantly higher expression of *Depdc1*, *Nusap1*, *Spp1*, and *Rrm2* genes, relative to sham controls.
- **Dr. O'Banion:** Effect of Space Radiation on Innate Immune System Homeostasis Drives Immune and Endothelial Cell Dysfunction and Neurodegeneration
 - The key objective of this proposal is to evaluate dose- and time-dependent effects of simulated space radiation on multiple tissue (immune, brain) endpoints associated with normal aging.

To Be Started in 2024

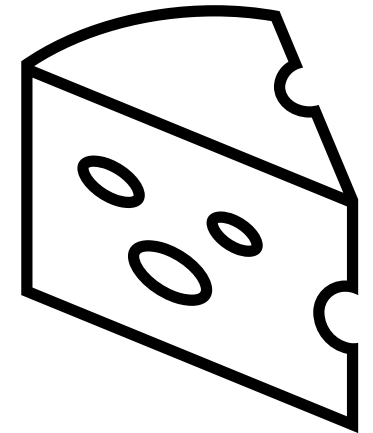
- **Dr. Lau:** Effects of Acute and Protracted Proton Radiation Exposure on Bone Health
- **Dr. Suman:** Senescent cell targeting to alleviate space radiation-induced neuroinflammation
- **Dr. Langen: Sex-Specific Biomarker Identification for Space Radiation-Induced Lymphoma**



Challenges Needed to Overcome



- **Timeframe from solicitation to ATP (16 Month)**
 - Waterfall approach
- **Attrition / Attraction**
- **How to design for the most impactful solicitations/studies**
 - \$\$\$\$
 - Large studies
- **Mindset (positive results, negative results, any results)**
- **How to manage all this data**
 - visualizations
- **What now issue with data**

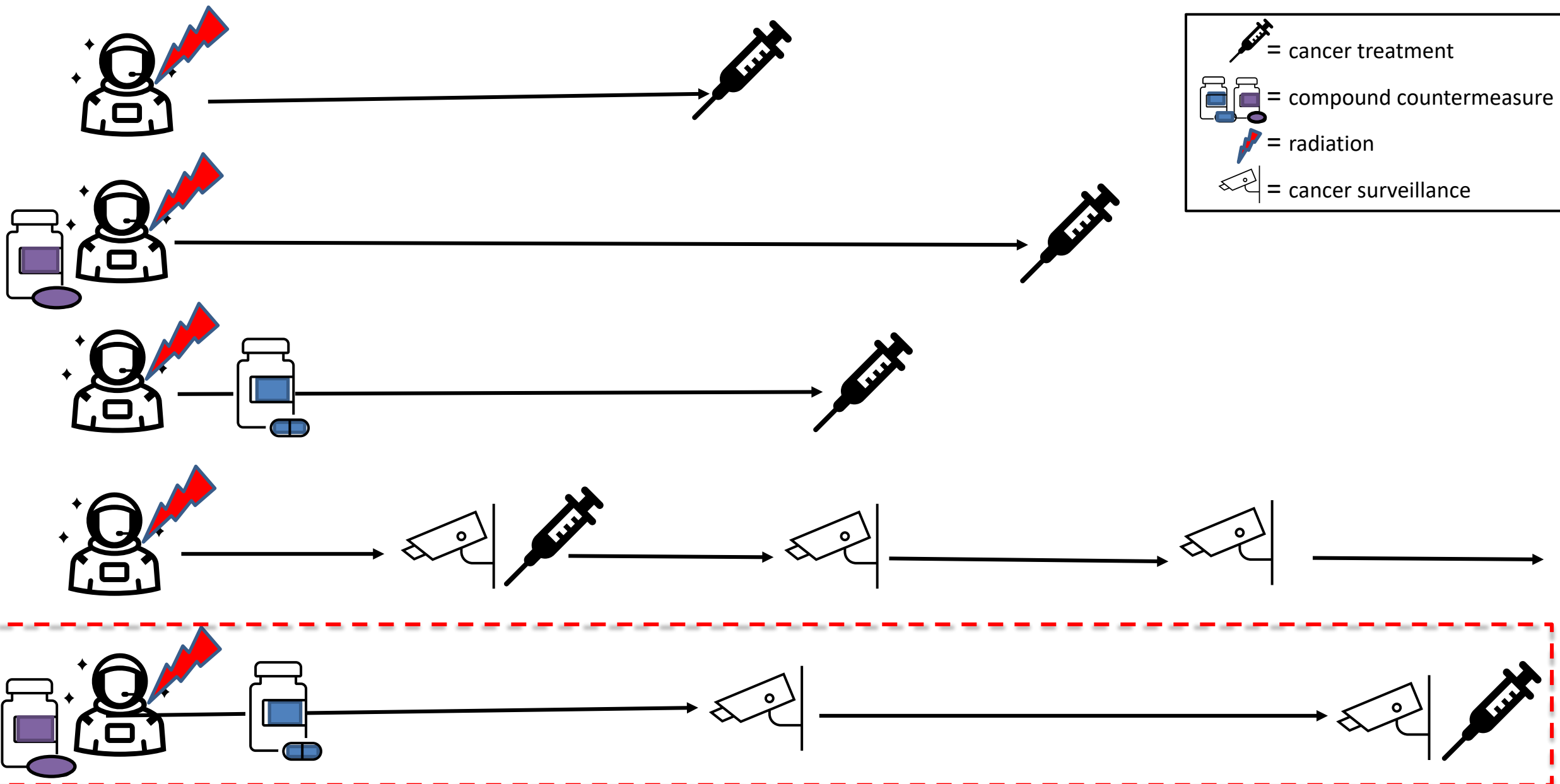


Questions?

jsc-hrp-space-radiation-element@mail.nasa.gov



Infographic of the Cancer Strategy





Backup



Drug Screening Initial Run Results

Cell Viability

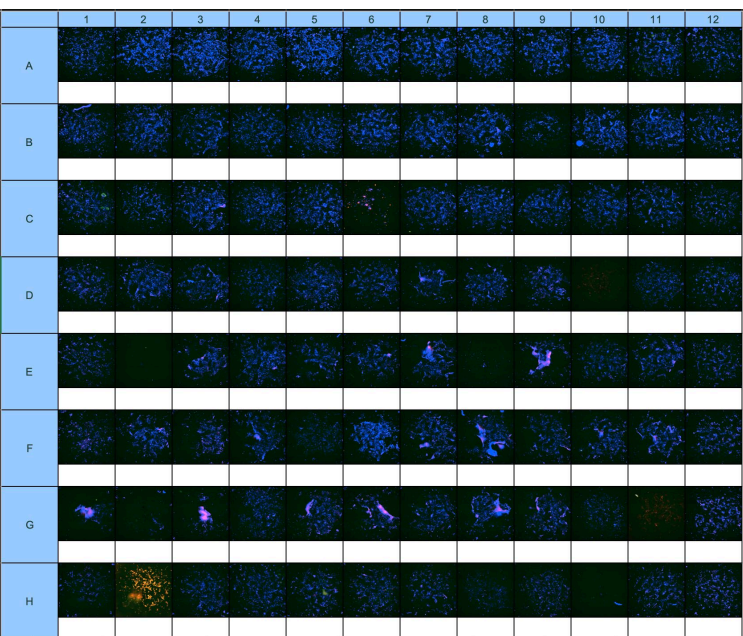
	1	2	3	4	5	6	7	8	9	10	11	12	Hoechst
A	4441	5183	5911	5120	5734	5243	4817	4970	4839	5125	4973	4424	
B	5971	6404	5244	5407	5545	6234	5520	5255	2837	5768	6116	4443	
C	5904	3614	6502	5962	6476	1470	6425	6404	5941	5894	5568	4260	
D	5057	6526	4638	5260	6599	5673	3176	4900	4598	1035	5040	4193	
E	5391	335	4941	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	Oxidative Stress			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	Dying/Dead Cells			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	





Submariners



- Little evidence for cognitive or behavioral changes in human epidemiological studies **relevant to spaceflight**
- Animal studies suggest potential impacts to health and performance
- Spaceflight exposures are experienced simultaneously
 - Environmental (radiation, air contaminants)
 - Psychological (confinement, isolation, hostile)
 - Physical (fatigue, high workload, sleep loss)

THE SOLUTION

- Leverage **robust interagency investment** to support epidemiologic study of nuclear submariners
 - Over \$1.5B across 12 agencies
- Many **neurological, behavioral, and cognitive impairment disorders** can be evaluated
 - Centers for Medicare and Medicaid Systems data represent essentially **all human diseases, conditions, and patient characteristics**, coupled with pharmaceuticals such as sleep medication (e.g. Ambien®)

THE BIG PICTURE

- **Large cohort** (n=160,000 submariners from 1954+) with **extensive medical follow-up** (40-60 yrs) has the **statistical power** to **detect excess cases** of health outcomes and associations with radiation as well as multiple occupational stressors
- Provides required scientific foundation to **scale animal findings** and **develop risk assessment** for spaceflight exposures



Submariners – Contributions and Cumulative Doses

Navy Career Dose (mSv)

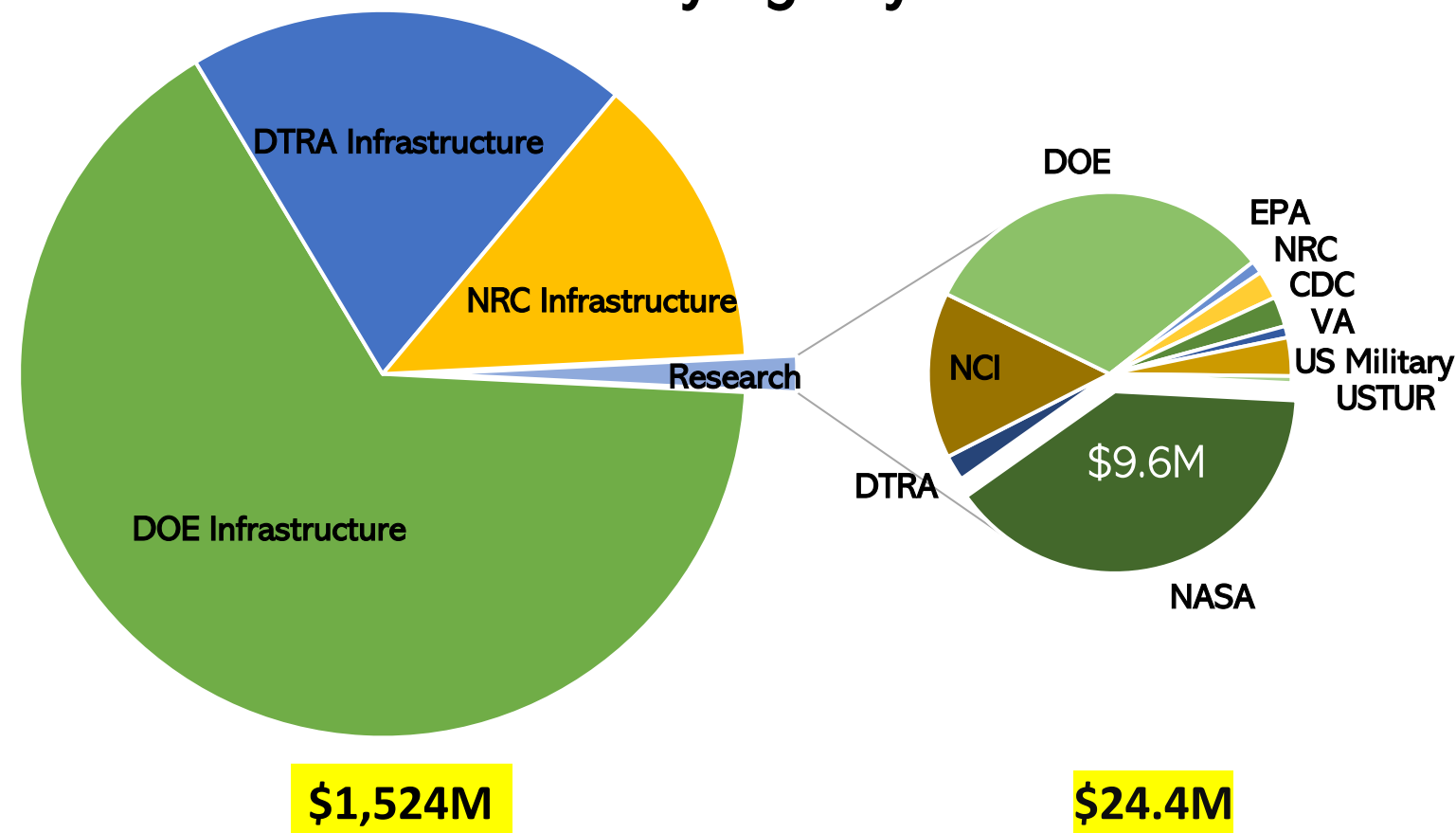
Photon			Neutron		
Dose (mSv)	Frequency	Precent	Dose (mSv)	Frequency	Percent
0 - < 0.2	3,975	3.53	0.01 - < 0.1	9,368	27.90
0.2 - < 1	40,067	35.58	0.1 - < 1	17,842	53.14
1 - < 2	19,102	16.96	1 - < 2	2,883	8.59
2 - < 5	18,789	16.68	2 - < 5	2,160	6.43
5 - < 10	12,163	10.80	5 - < 10	955	2.84
10 - < 20	9,978	8.86	10 - < 20	354	1.05
20 - < 50	6,710	5.96	20 - < 50	15	0.04
50 - < 100	1,581	1.4			
100 - < 250	248	0.22			
250 - < 1,000	9	0.01			



Submariners – Contributions and Cumulative Doses

Interagency Buy-In and contributions

Estimated Million Person Study Contributions to Date by Agency





Funding Priorities

Dose Rate Effects, Radiation Quality

Surrogate Biomarkers

Individual Susceptibility

**Countermeasures (non FDA or IND approved),
Solar Particle Events, Biodosimetry**