



Reduction of uncertainty of radiation health risk assessment

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Manned space exploration in China



SZ-12

2021.6.12



SZ-13

2021.10.16



SZ-14

2022.6.5



Lab

2021.5.28



SZ-10

2013.6.11



SZ-5

2003.10.15



SZ-6

2005.10.12



SZ-7

2008.9.25



CSS

2021.7.24



Moon base



苏州大学 苏州医学院

Suzhou Medical College of Soochow University



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School of Radiation Medicine & Protection

Manned space exploration in China

Launch site



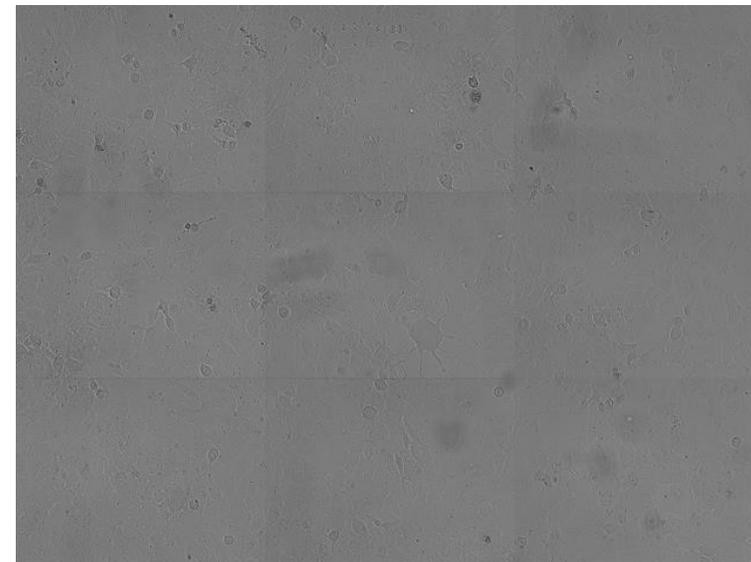
Prelaunch



Onboard



Sampling



28-day automatic cell culture



Space radiation environment

Difference in QUANTITY

Earth

1g
~2.4 mSv/year

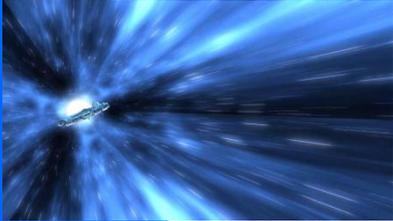
CSS

0g
<1 mSv/day

Moon

1/6g
~2 mSv/day

Interstellar travel


0g
~3 mSv/day

Mars

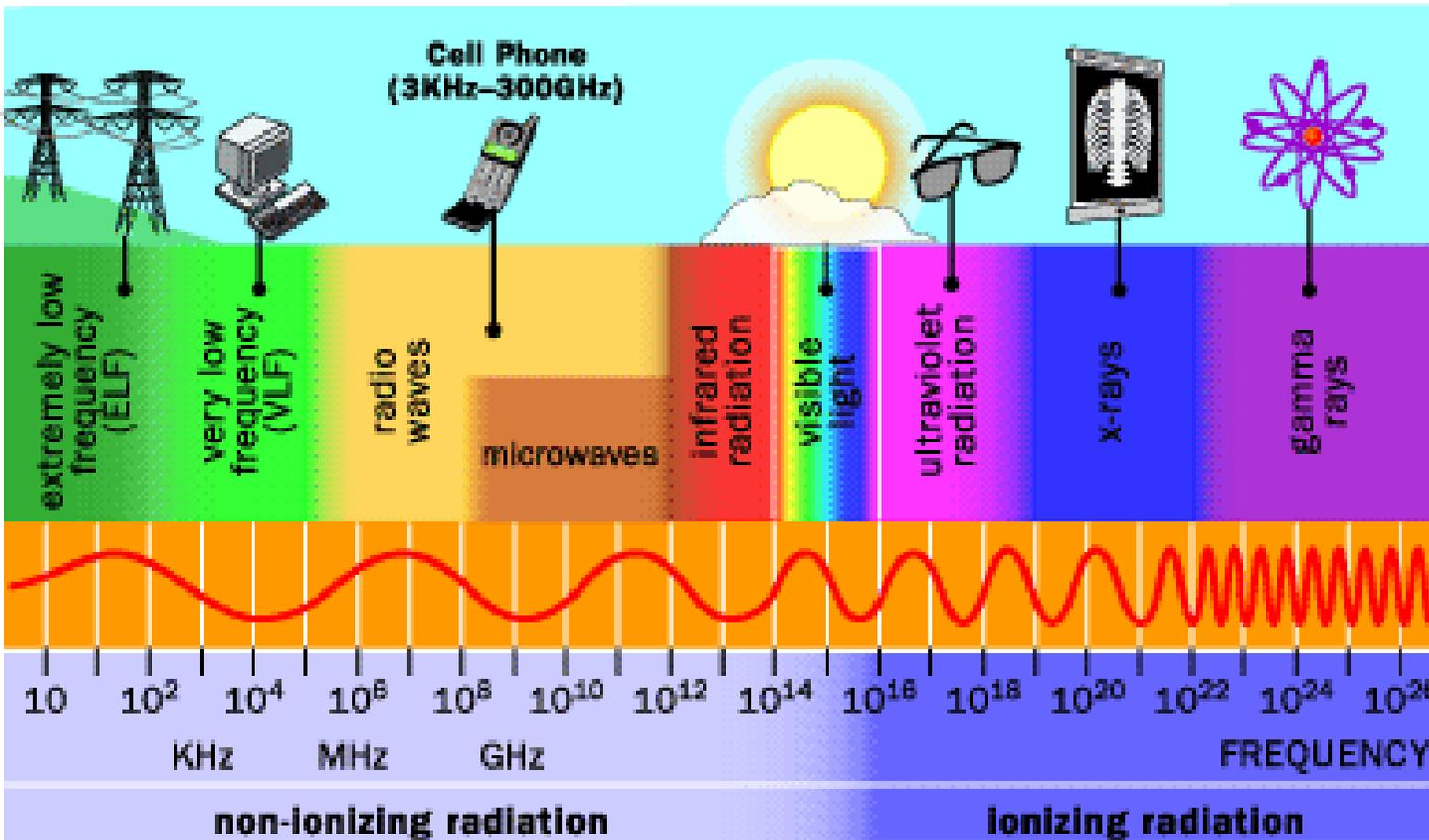
1/3g
~3 mSv/day



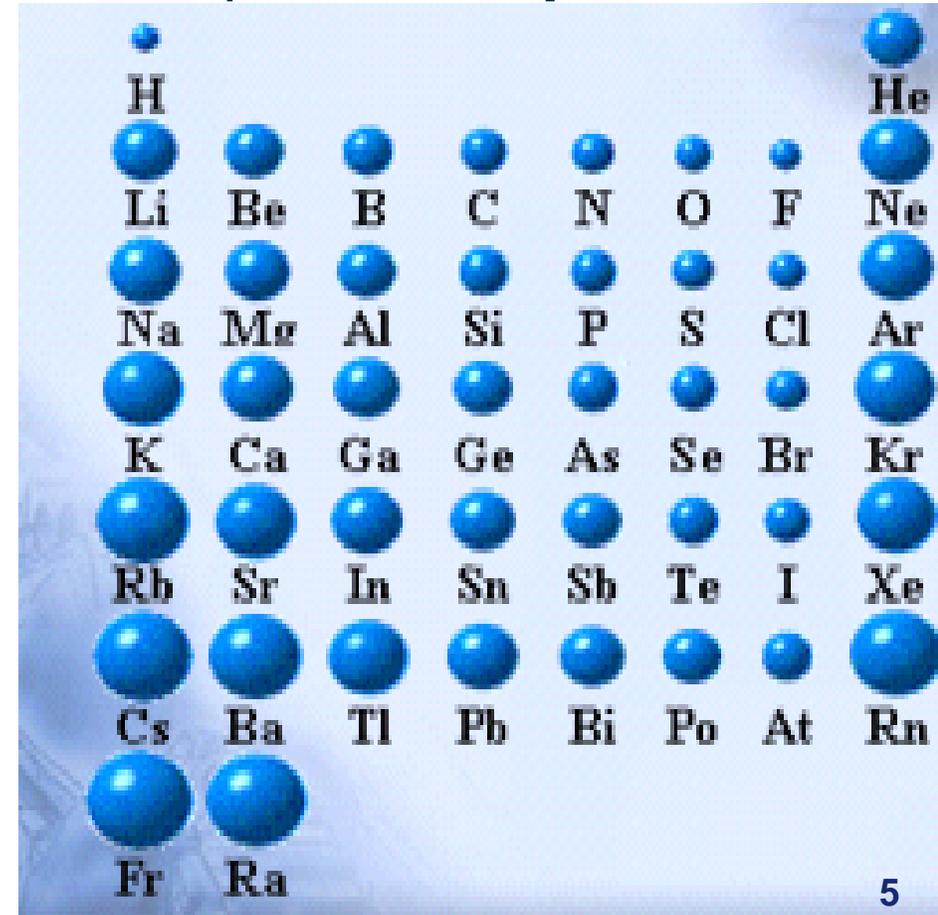
Space radiation environment

Difference in QUALITY: type & energy

Earth: Magnetic wave

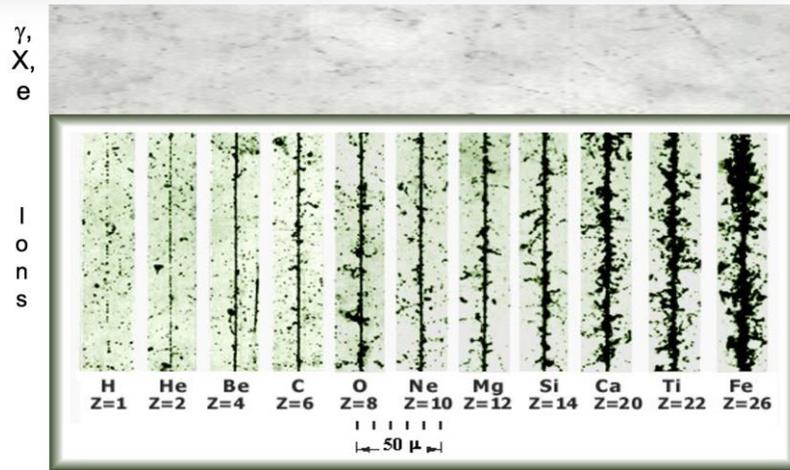


Space: HZE particles

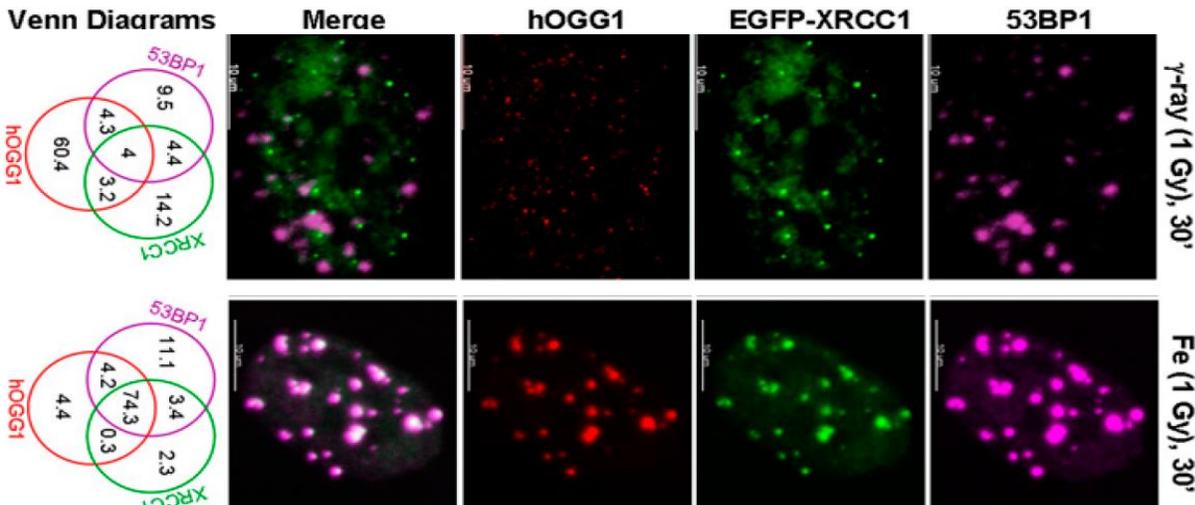
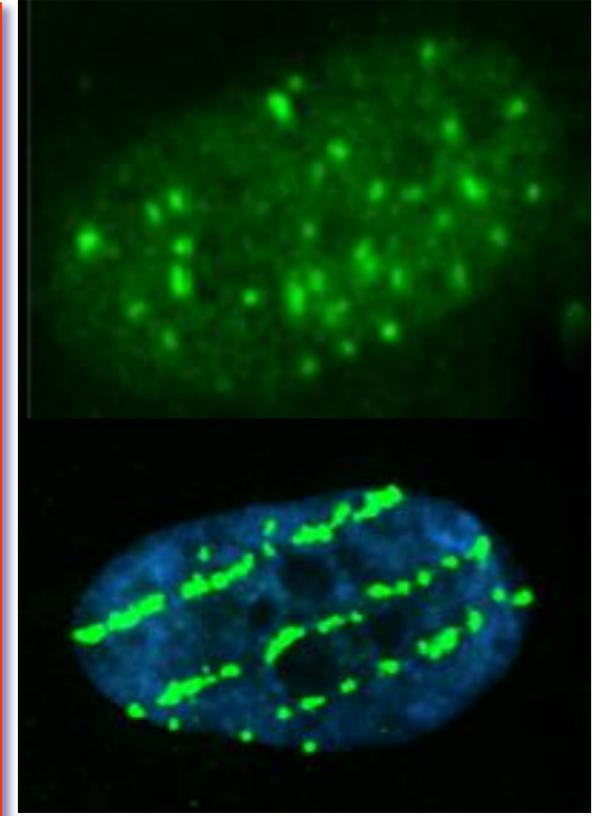
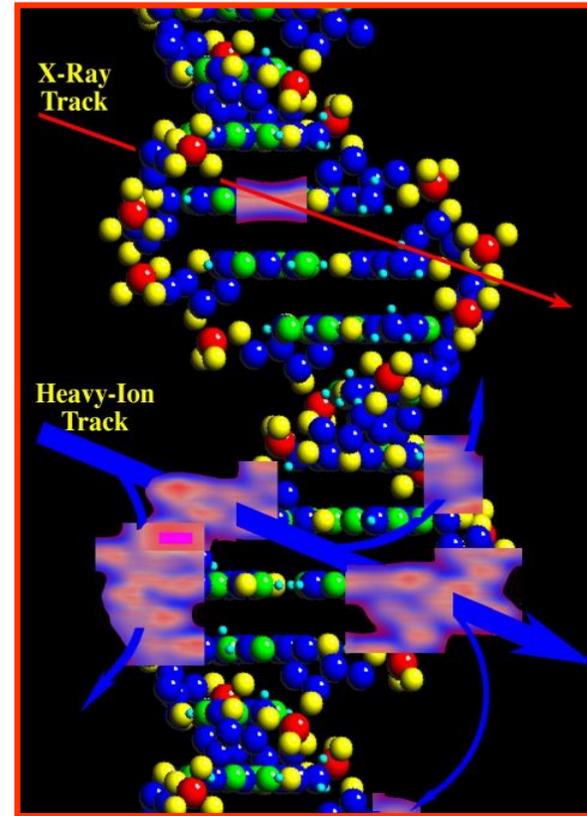


Space radiation environment

Difference in QUALITY: bioeffects



HZE particles: Clustered DNA damage

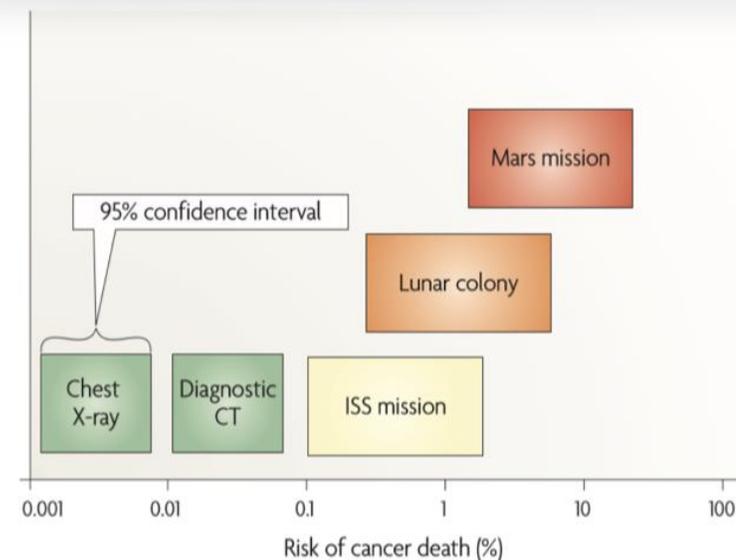


Cucinotta & Durante. Lancet Oncol, 2006

Asaithambi et al. PNAS, 2011

Cancer risk of space radiation

Number of astronauts / control participants	No. malignant neoplasms	%	Source
195 (selected 1959 - 1991)	1	0.5	Peterson <i>et al.</i> , 1993
195 (selected 1959 - 1991)	4	2.1	Hamm <i>et al.</i> , 2000
312 (1959-2000)	14	4.5	Fisher 2003
928 LSAH comparison participants	26	2.8	Fisher 2003



Nature Rev Cancer, 2008

	Absorbed dose (Gy)*	Effective dose (Sv)	Fatal risk, % (95% CI)	
			Men (age 40 years)	Women (age 40 years)
Lunar mission (180 days)	0.06	0.17	0.68% (0.20-2.4)	0.82% (0.24-3.0)
Mars orbit (600 days)	0.37	1.03	4.0% (1.0-13.5)	4.9% (1.4-16.2)
Mars exploration (1000 days)	0.42	1.07	4.2% (1.3-13.6)	5.1% (1.6-16.4)

Calculations are at solar minimum, where GCR dose is highest behind a 5 g/cm² aluminium shield. *Mean for tissues known to be sensitive to radiation and at risk of cancer² including lung, colon, stomach, bladder, bone marrow, and breast and ovaries in women.^{2,3} Competing causes of death are included in calculations because they decrease risk probabilities if high (ie, >5%).

Table: Radiation risks for men and women on missions to the moon or Mars *Lancet*, 2006

ABSTRACT

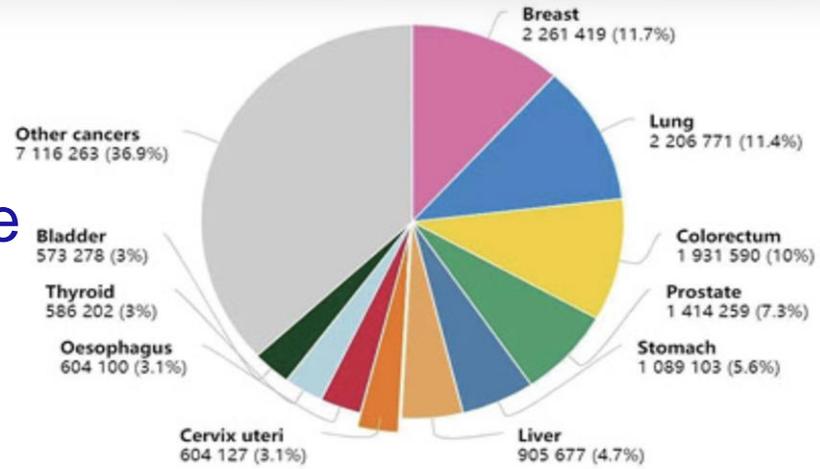
LSSR, 2018

Cancer is an important long-term risk for astronauts exposed to protons and high-energy charged particles during travel and residence on asteroids, the moon, and other planets. NASA's Biomedical Critical Path Roadmap defines the carcinogenic risks of radiation exposure as one of four type I risks. A type I risk represents a demonstrated, serious problem with no countermeasure concepts, and may be a potential "show-stopper" for long duration spaceflight. Estimating the carcinogenic risks for humans who will be exposed to heavy ions during deep space exploration has very large uncertainties at present. There are

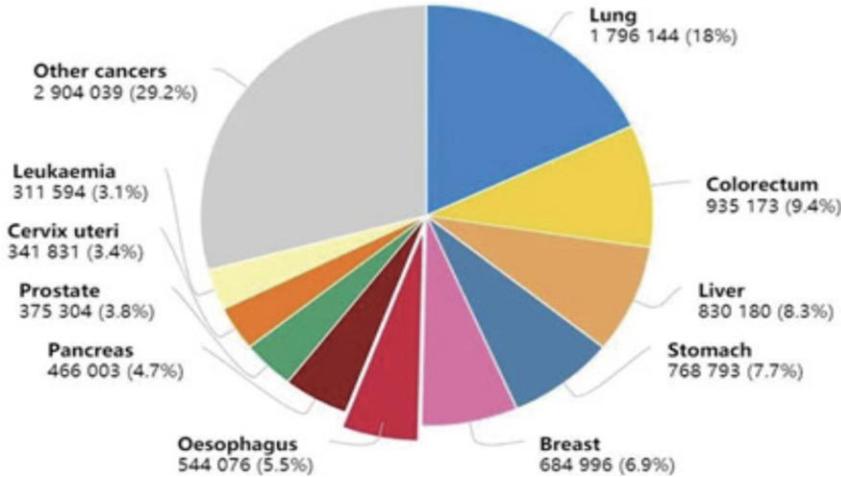


Cancer risk of space radiation

Incidence

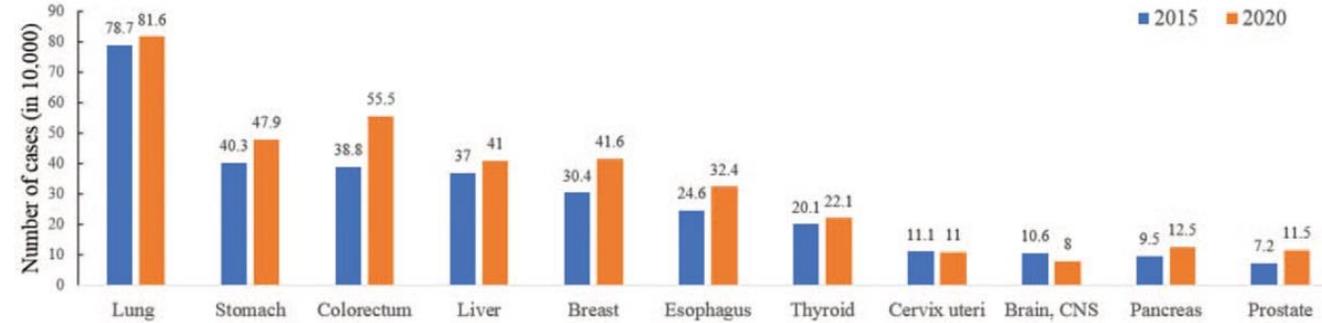


Mortality

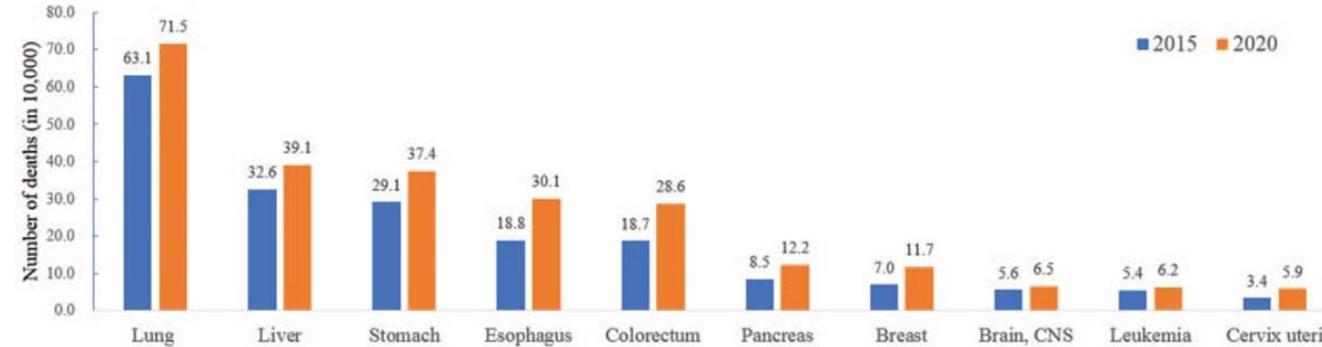


Cancer: a killer
CA J Cancer Clin 2021

A



B



23.6% new cases, 30% death in China
Chinese Med J-Peking 2021



Cancer risk assessment

1. Risk assessment:

- NASA
- ESA, RSA, CSA, JAXA
- ICRP

2. Health monitoring:

- Biomarkers
- Tools

3. Countermeasures:

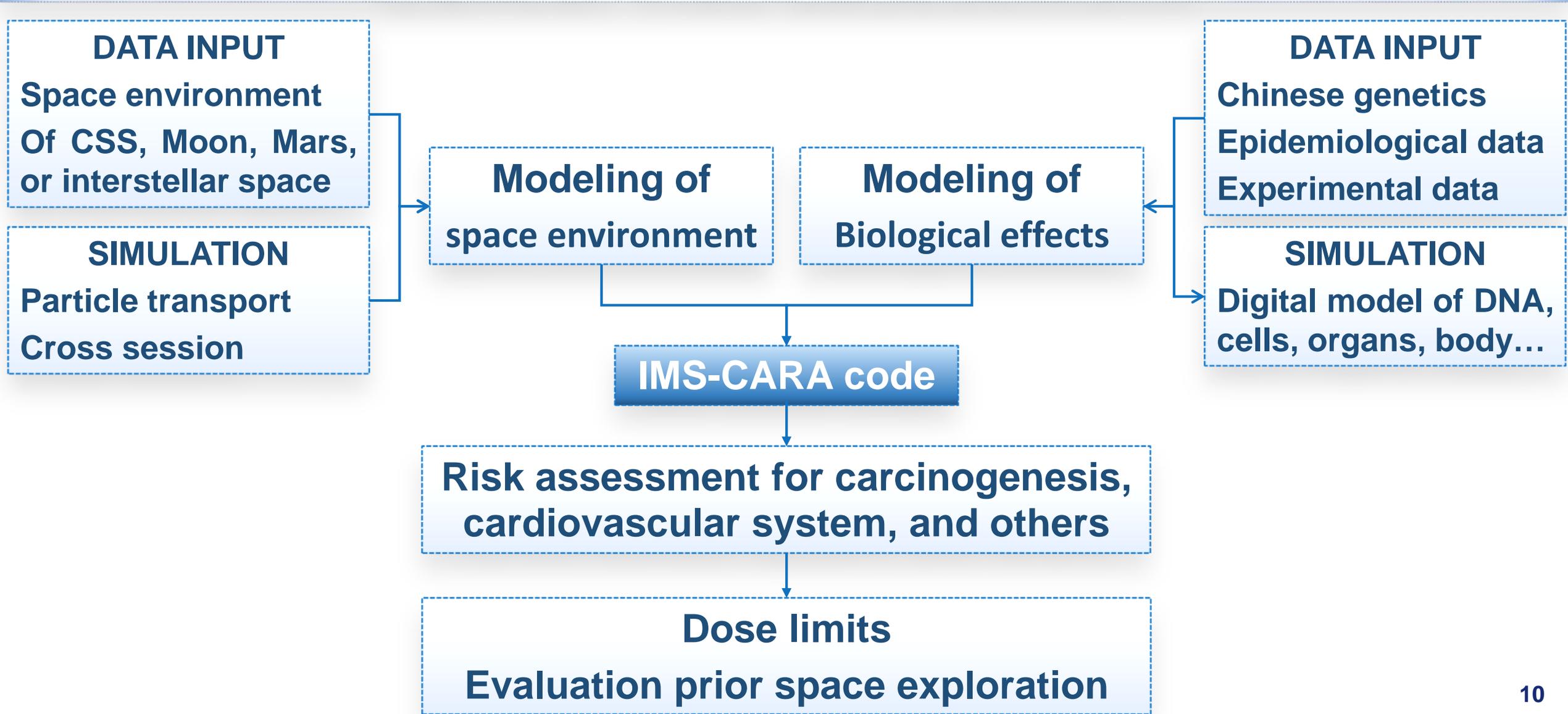
- Physical
- Biomedical

限值分类		限值 (Sv)					
部位	时间	NASA	China	RSA	ESA	CSA	JAXA
眼睛	30 d	1 ^a	0.6	0.5	0.5	1	0.5
	1 年	2 ^a	0.75	1	1	2	2
	职业生涯	4 ^a	-	2	2	4	5
皮肤	30 d	1.5 ^a	0.2	1.5	1.5	1.5	2
	1 年	3 ^a	0.8	3	4	3	7
	职业生涯	6 ^a	-	6	/	6	20
骨髓	30 d	0.25 ^a	-	0.25	0.25	0.25	/
	1 年	0.5 ^a	0.2	0.5	0.5	0.5	0.5
全身有效剂量限值	职业生涯	区分年龄/性别/吸烟给出个性化限值	0.5	1	0.6	1	2
		统一限值 0.6	-				
	1989 年 9 月特大 SPE	0.25					

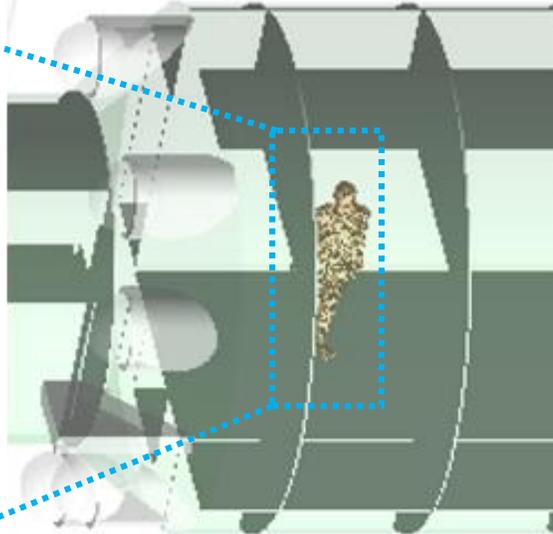
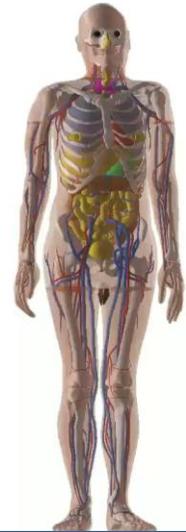
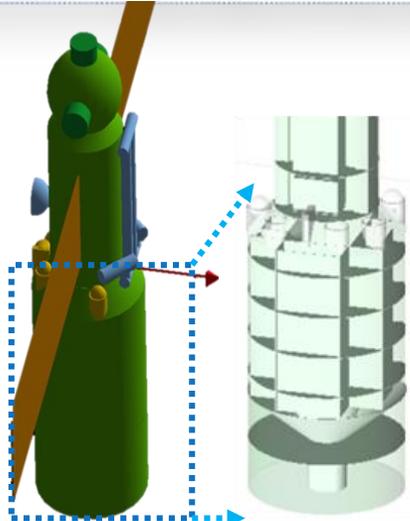
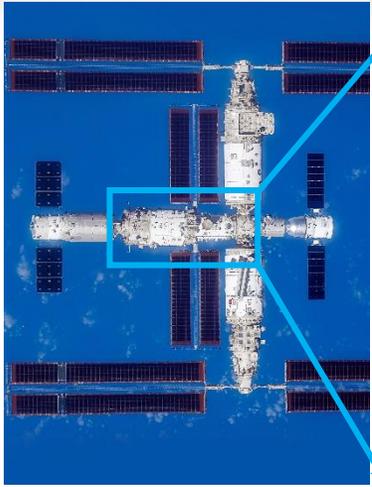
《中华放射医学与防护杂志》2025



Cancer risk assessment

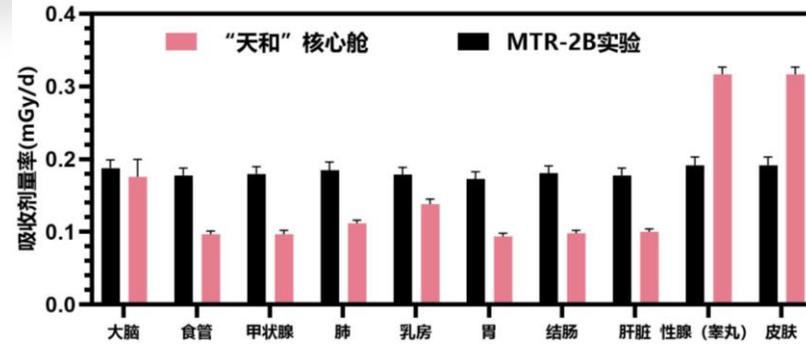


Cancer risk assessment



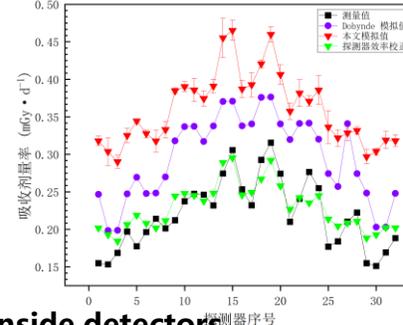
Taikongnaut

CSS core module

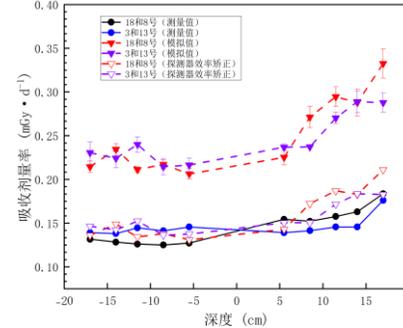


沈江燕等, 辐射防护, 2023

Surface detectors

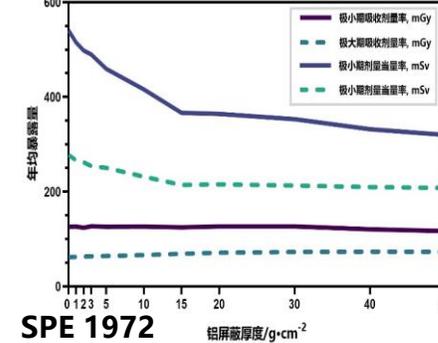


Inside detectors

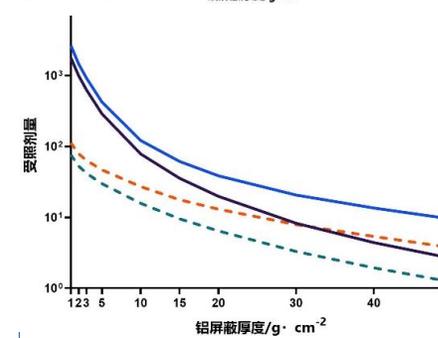


LEO

GCR

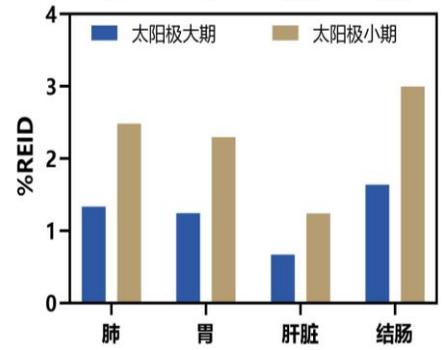
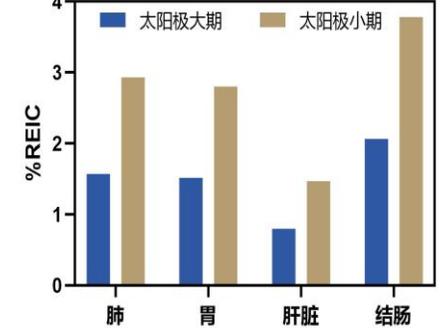


SPE 1972



Deep space

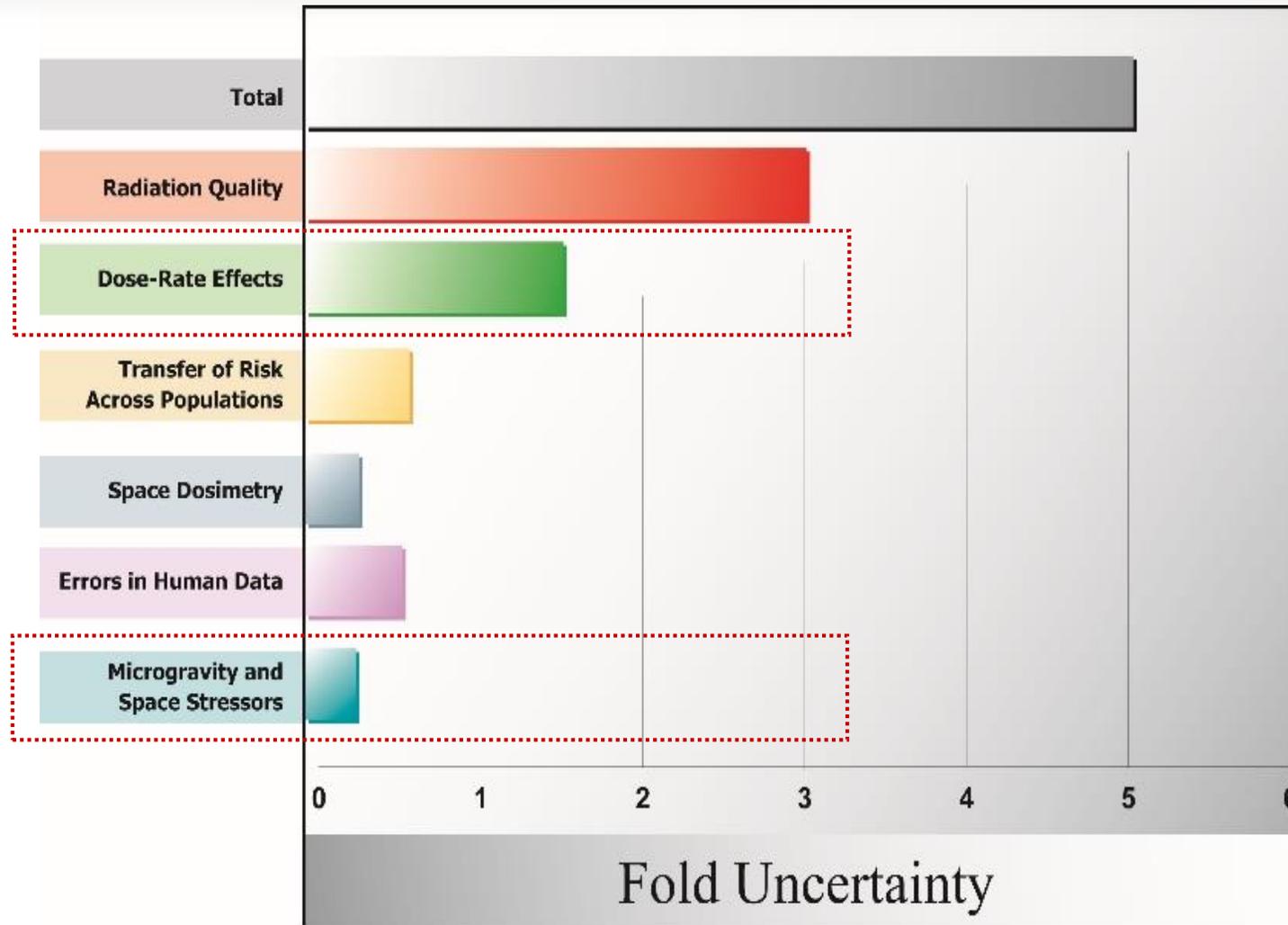
30-year male Taikongnauts



Risk of 600 days



Cancer risk assessment



Nature Reviews Cancer, 2008



Data we obtained

1. Effects of HZE particles:

Pei W, Zhou G*, et al. British Journal of Cancer 2025

Hu W, Zhou G*, et al. Cell Physiol Biochem 2018

Ding N, Zhou G*, et al. Advances in Space Research 2013

Su F, Zhou G*, et al. Radiation Oncology 2010

Zhou G, et al. Advances in Space Research 2010

2. Effects of mixed exposures:

Zhou G*, et al. Radiation Research 2006

3. Combined effects of microgravity and radiation:

Ding Y, Hu W, et al. NPJ microgravity 2025

Tan S, Hu W, et al. NPJ microgravity 2018

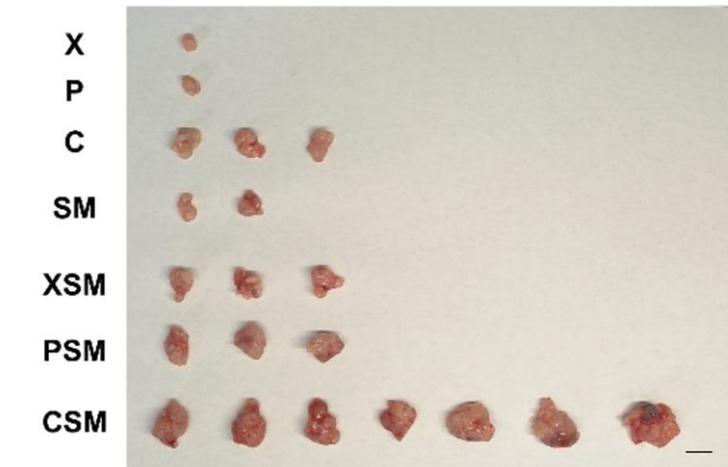
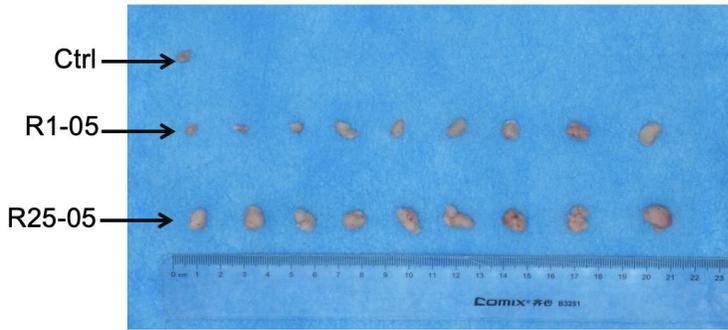
Xu D, Zhou G*, et al. J Radiat Res 2014

Hu W, Zhou G*, et al. J Radiat Res 2014

4. Bystander effects:

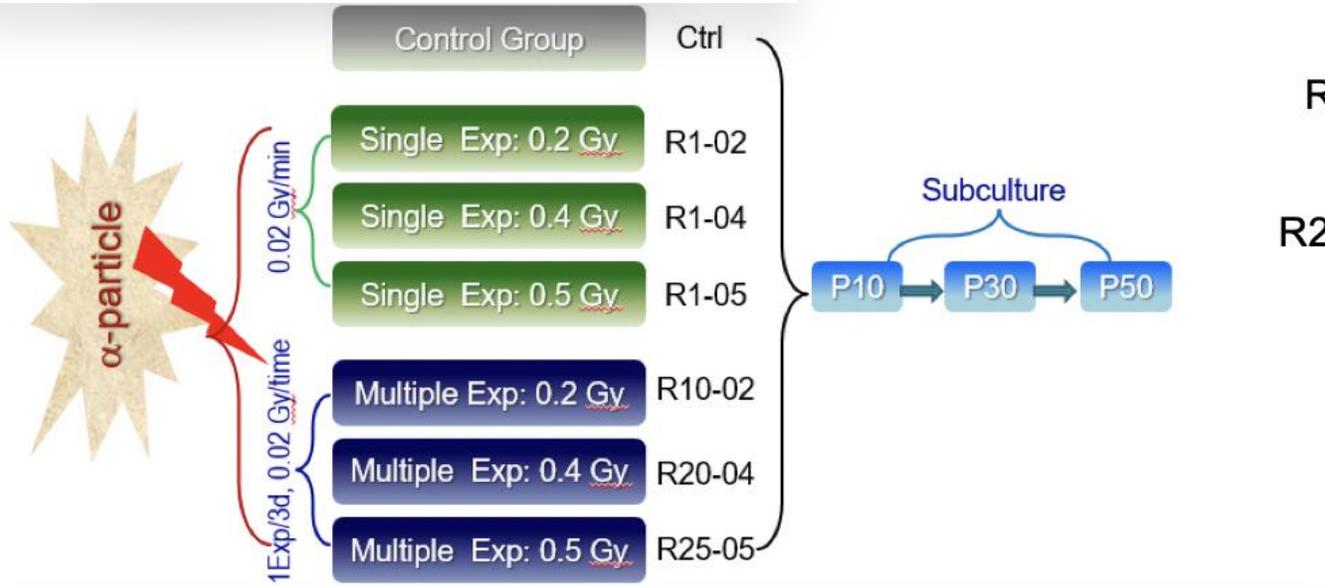
Xu Y, Hu W, et al. NPJ Microgravity 2025

Hu W, Zhou G*, et al. RNA Biology 2014



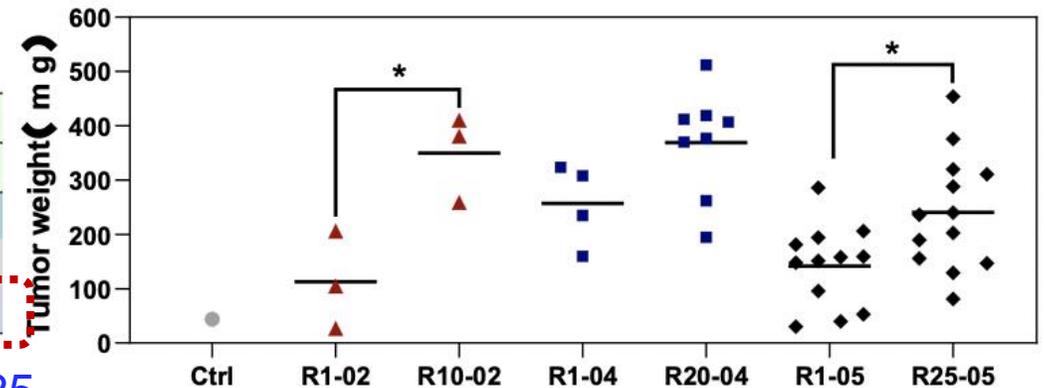
Carcinogenesis of Space radiation

Impact of dose rate



	Ctrl	Single irradiation (Gy)			Long-term irradiation (Gy)		
		0.2	0.4	0.5	0.2	0.4	0.5
No. nodules	2	4	5	12	4	8	13
Injection points	38	25	25	24	25	25	24
Nodule forming rate	5%	16%	20%	50%	16%	32%	54%

Li et al. British J Cancer, 2025

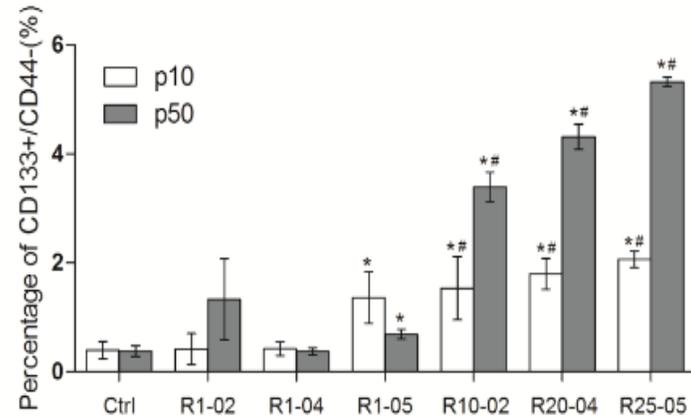
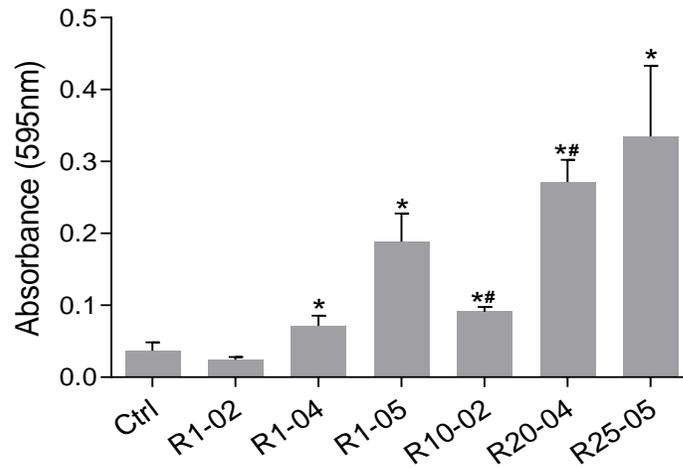
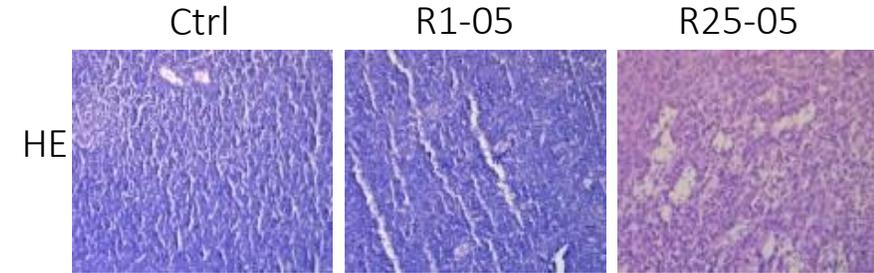
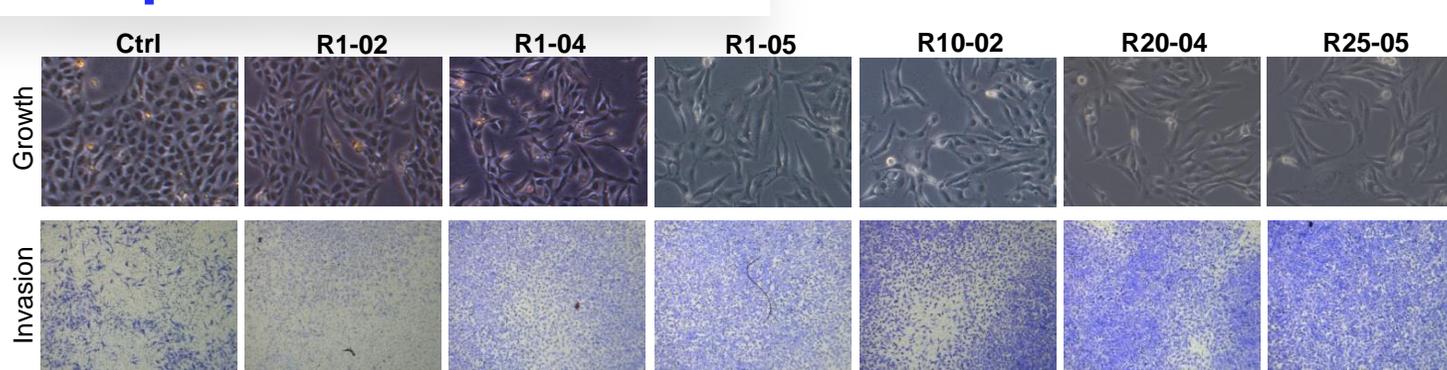


➤ Low dose-rate exposure didn't increase the risk but enhance the malignancy of cancer.

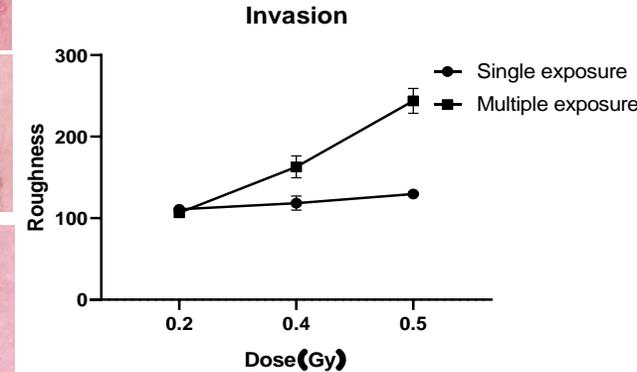
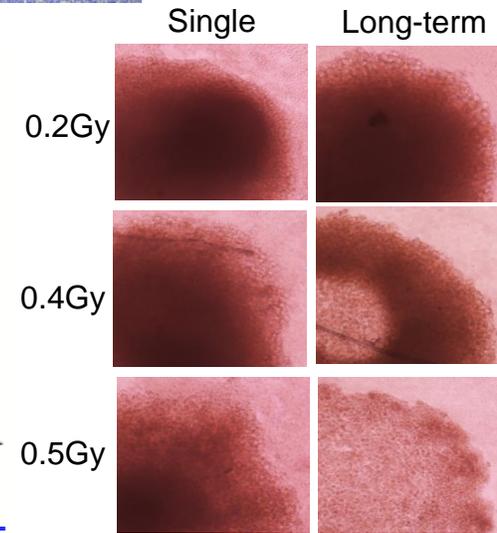


Carcinogenesis of Space radiation

Impact of dose rate



Li et al. British J Cancer, 2025

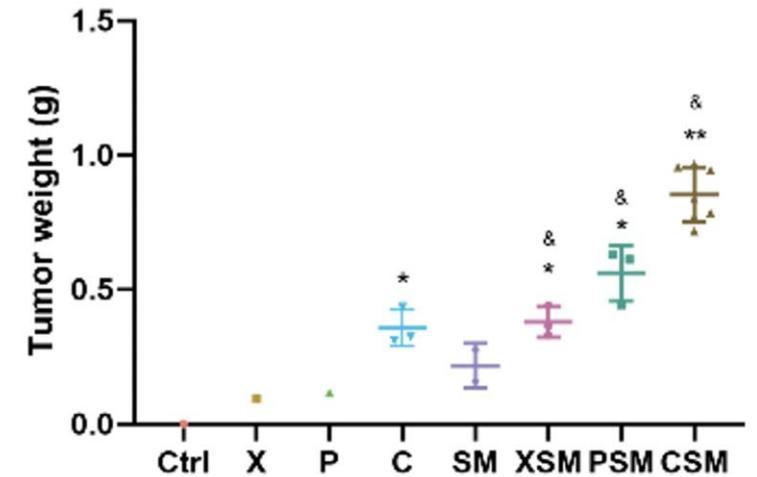
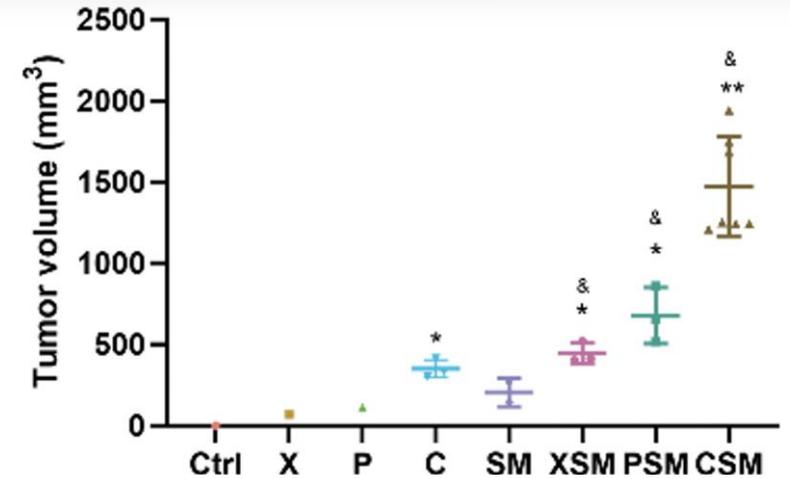
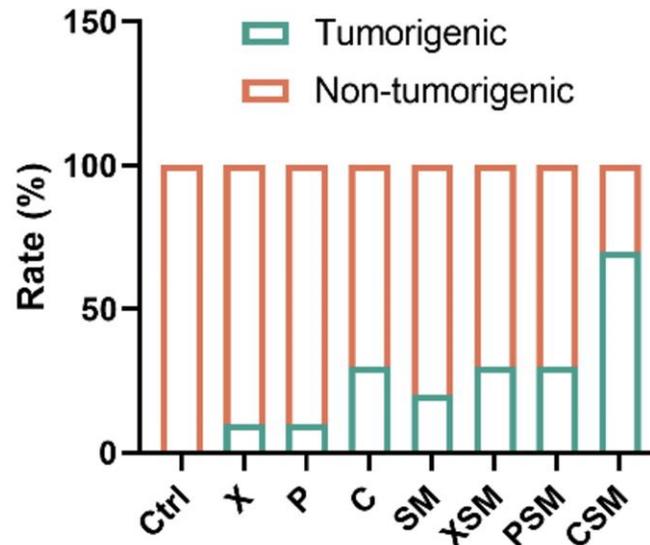
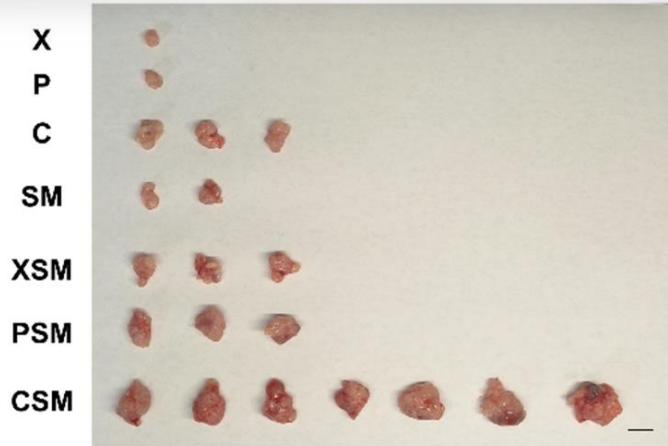
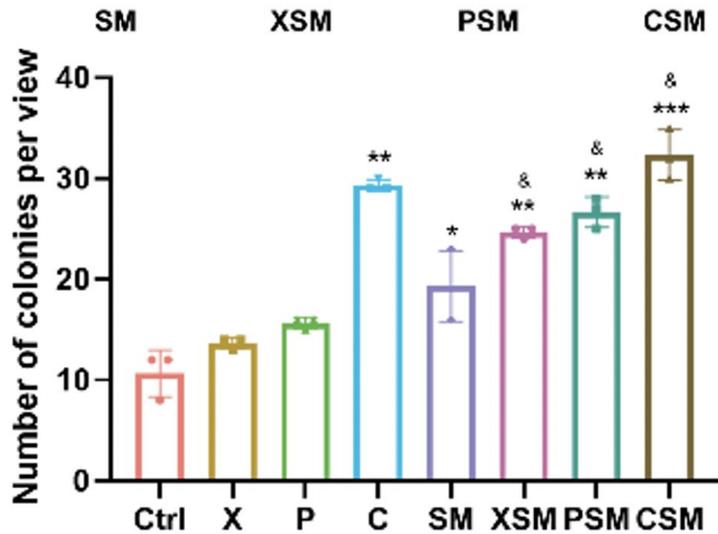
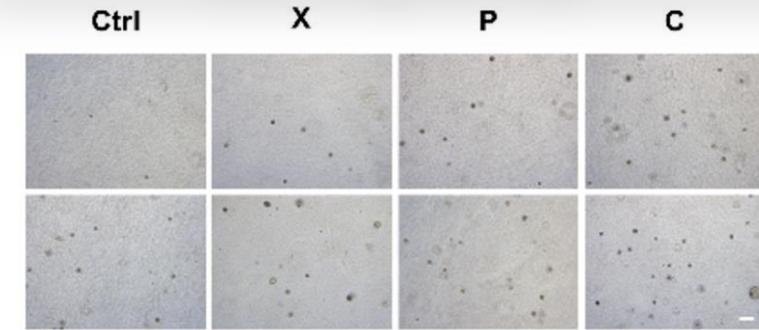


➤ Low dose-rate exposure didn't increase the risk but enhance the malignancy of cancer.



Carcinogenesis of Space radiation

Microgravity



Ding et al. NPJ Microgravity, 2025

➤ Simulated microgravity enhances radiation-induced carcinogenesis.



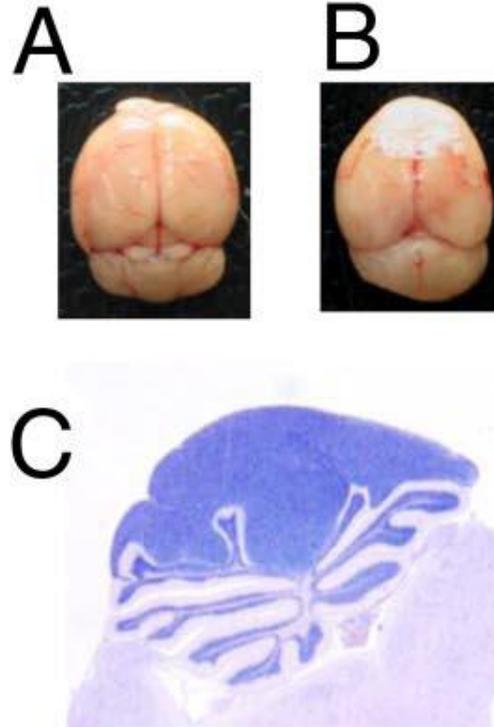
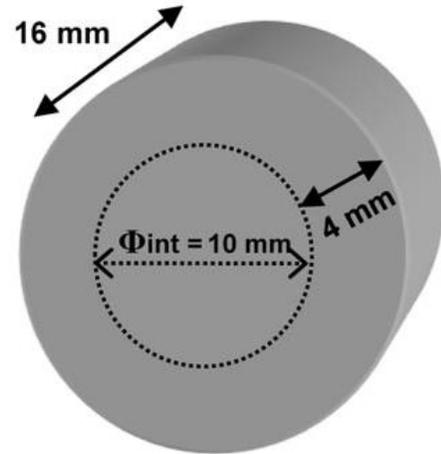
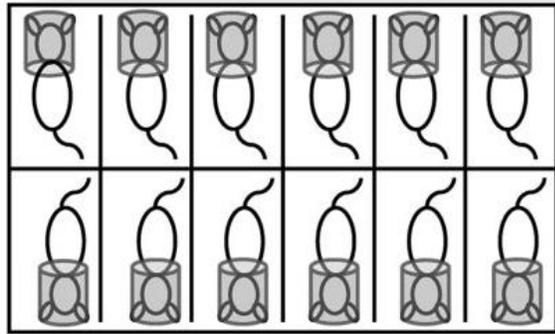
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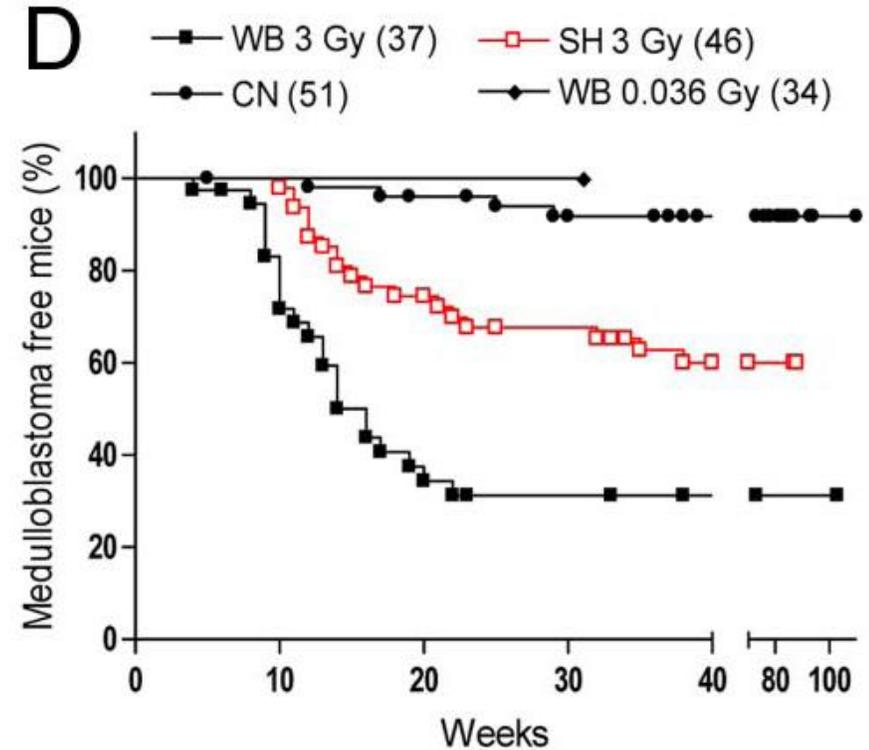
Carcinogenesis of Space radiation

Bystander effects



Medulloblastoma

1. Neonatal (Day 2 with 3 Gy)
2. Heterozygous ($Ptch1^{+/-}$)
3. Half body irradiation

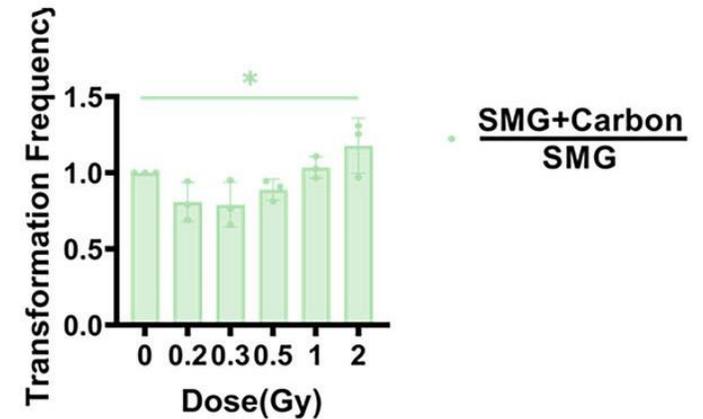
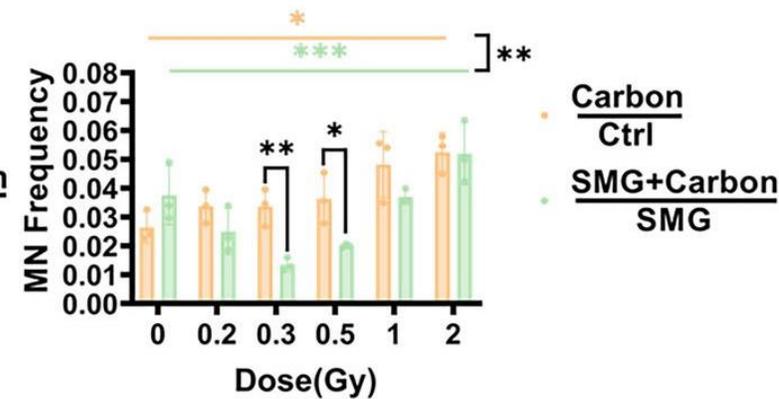
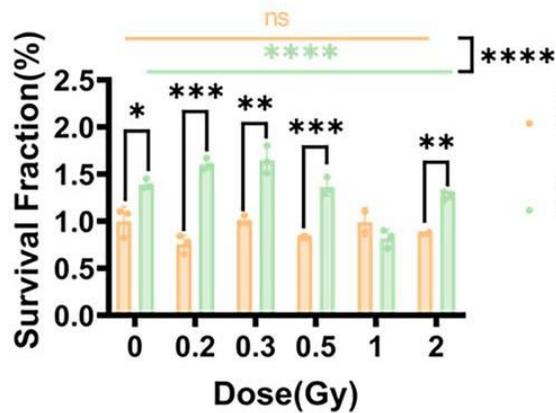
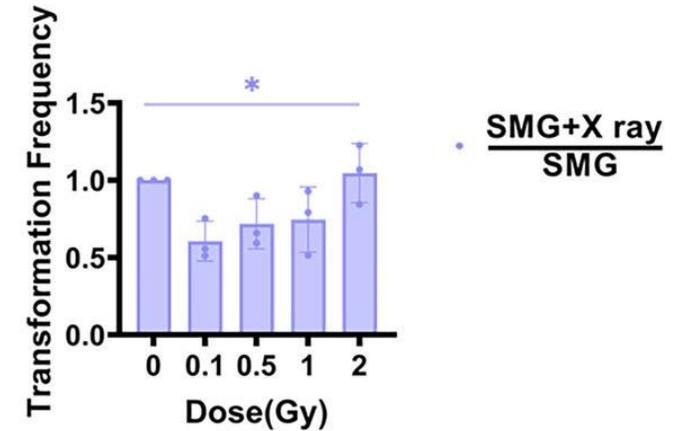
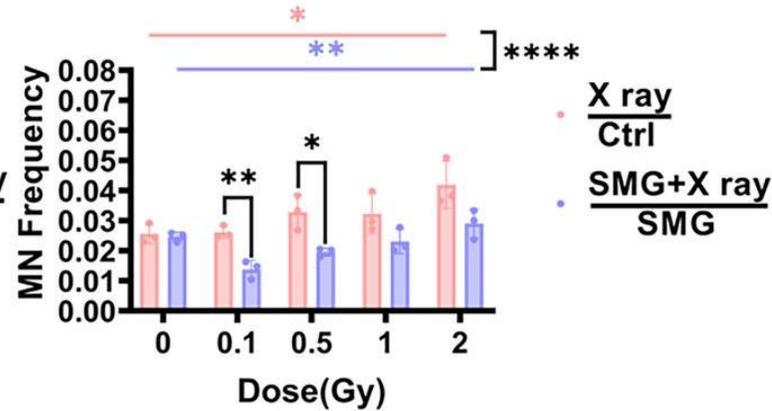
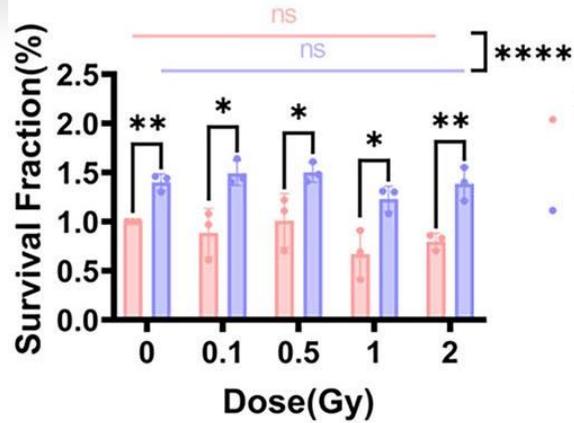


Mancuso *et al.* PNAS, 2008

➤ Half bottom exposure resulted in medulloblastoma.

Carcinogenesis of Space radiation

Microgravity

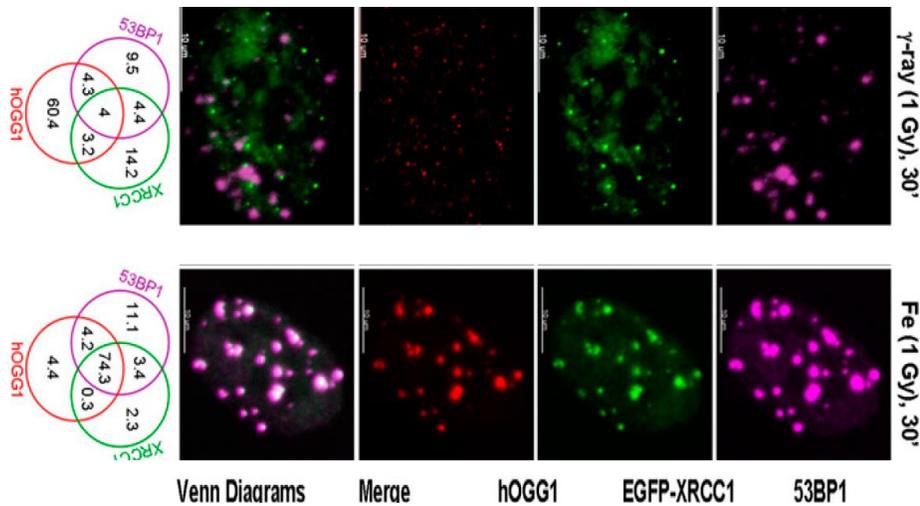
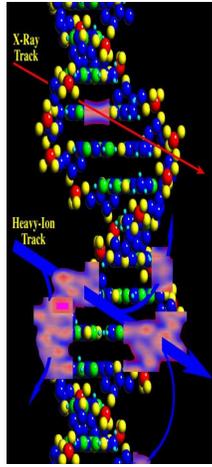


Ding *et al.* NPJ Microgravity, 2025

➤ Simulated microgravity eliminates radiation-induced bystander effects.



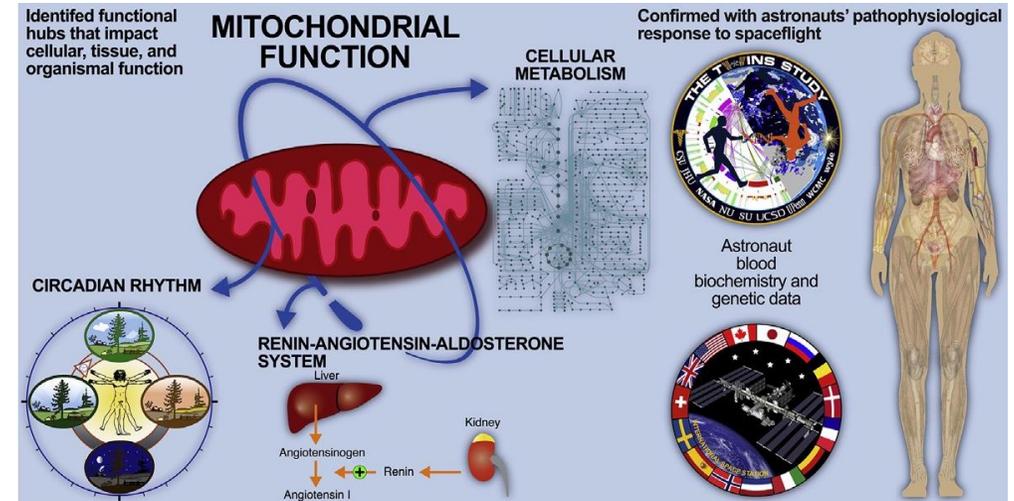
Mechanisms of IR-induced carcinogenesis



Lancet Oncol 2006

PNAS 2011

HZE particles induce clustered DNA Damages, which are hardly repairable.

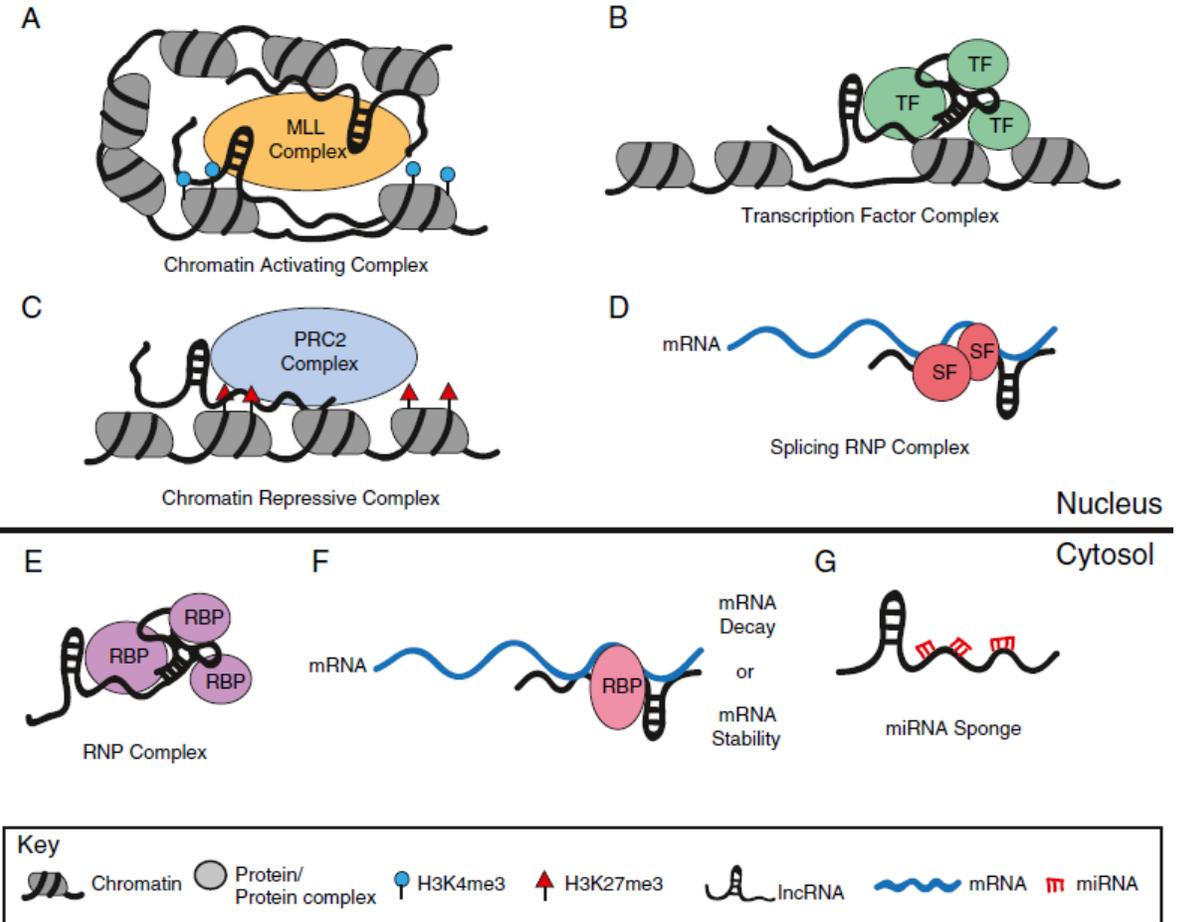
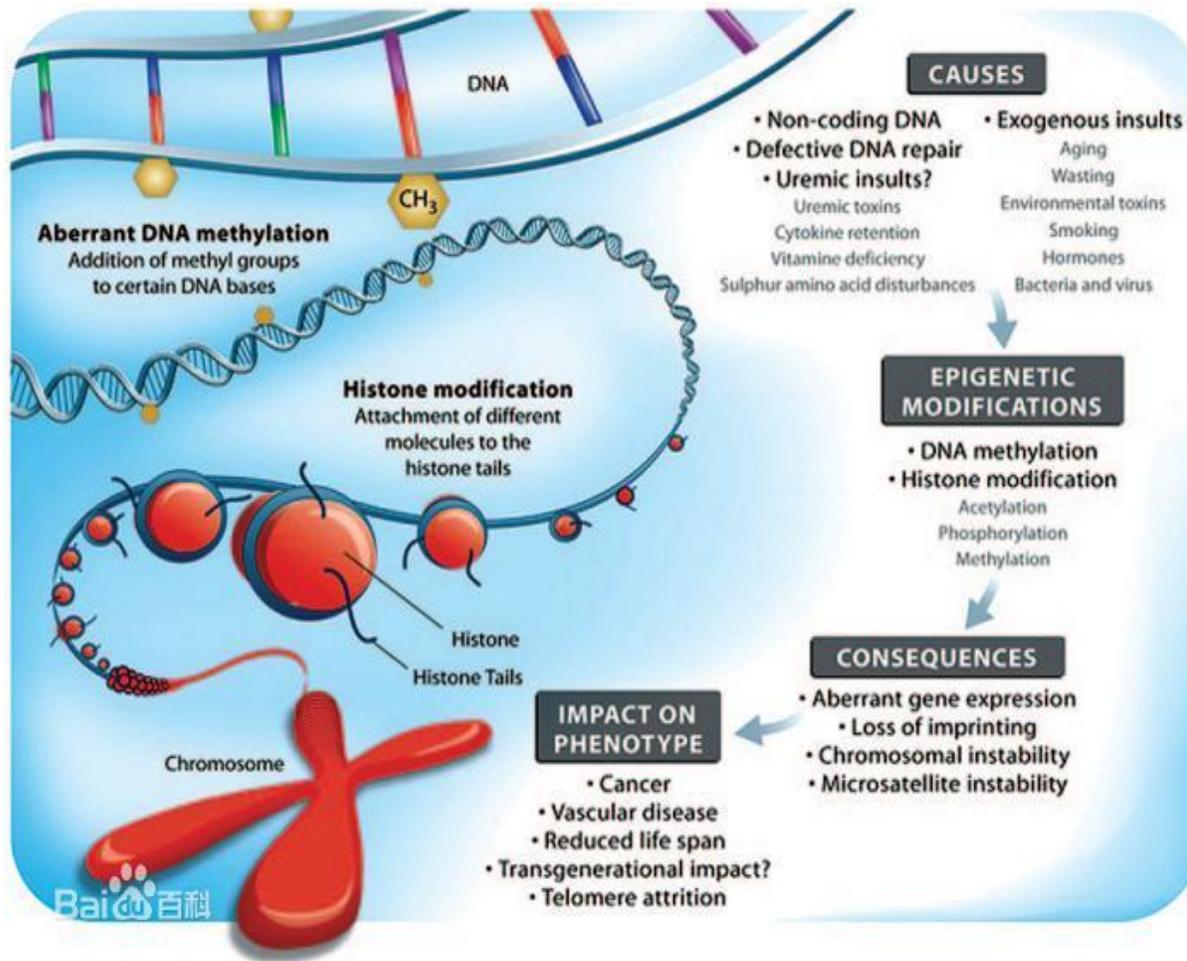


Cell 2020; Nature 2024

Mitochondria are a hub regulating biological response to space environment.

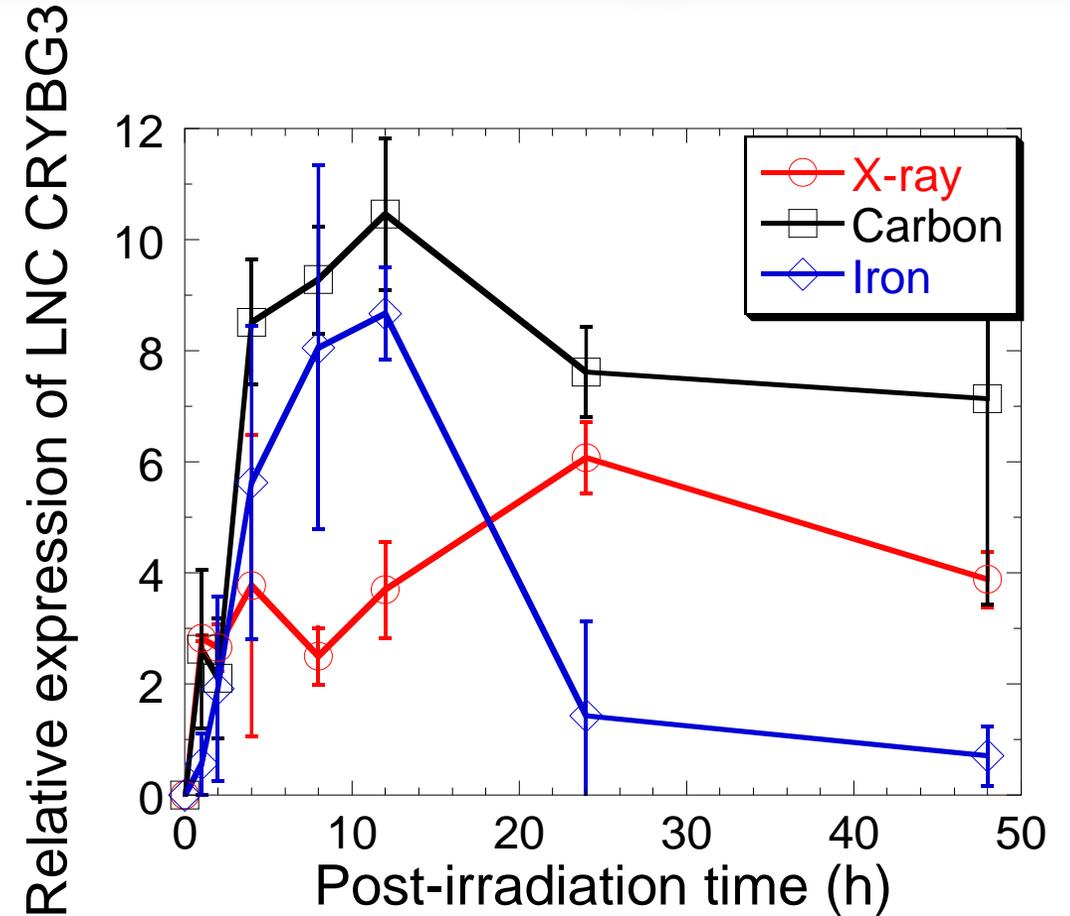
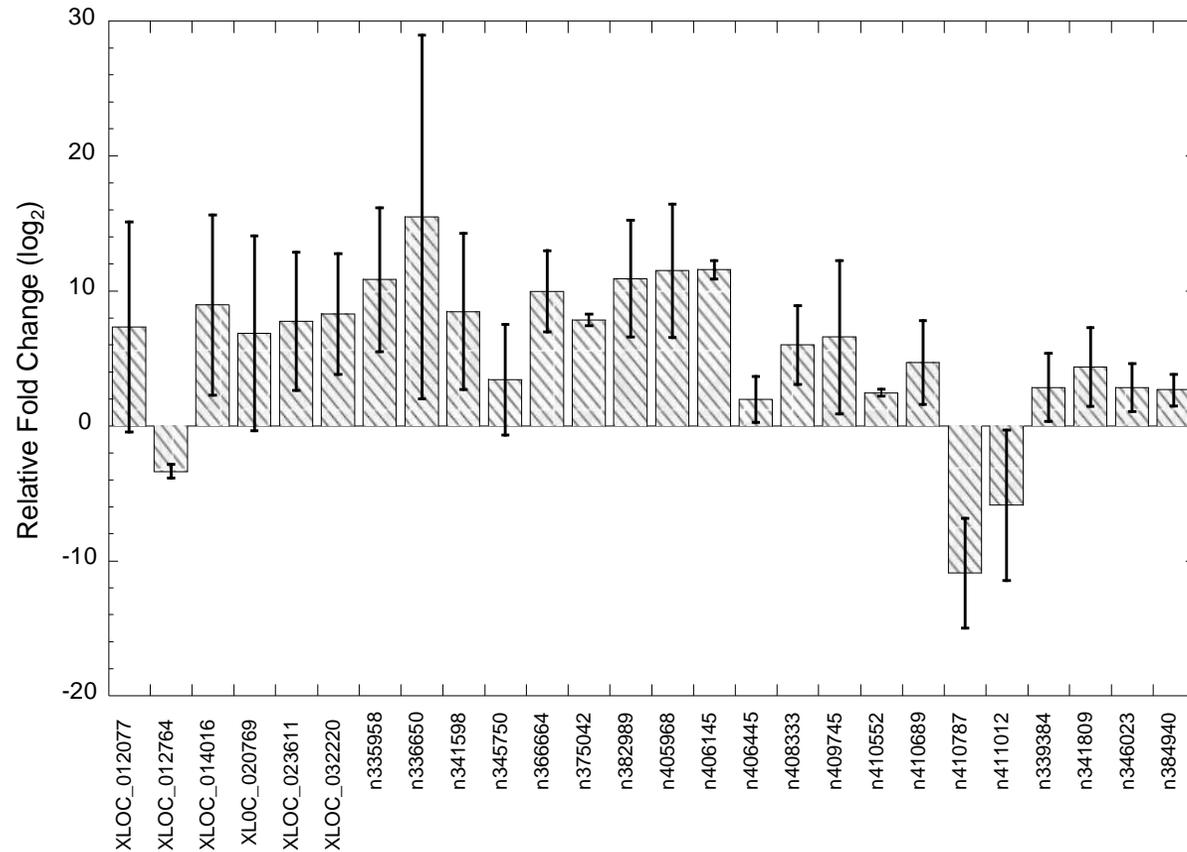


Mechanisms of IR-induced carcinogenesis



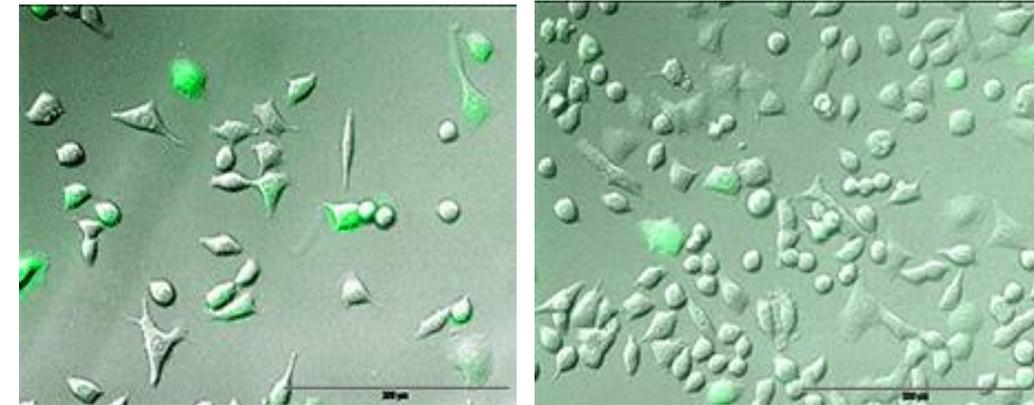
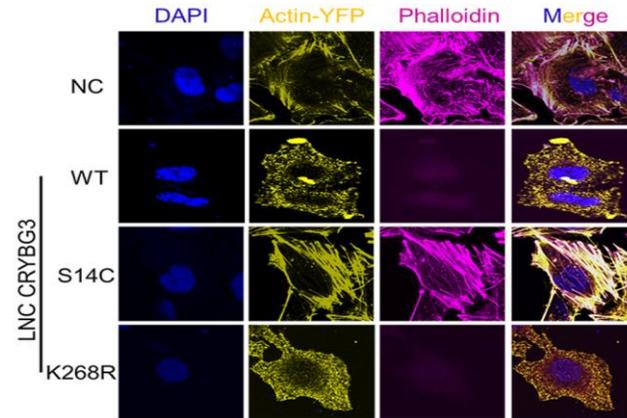
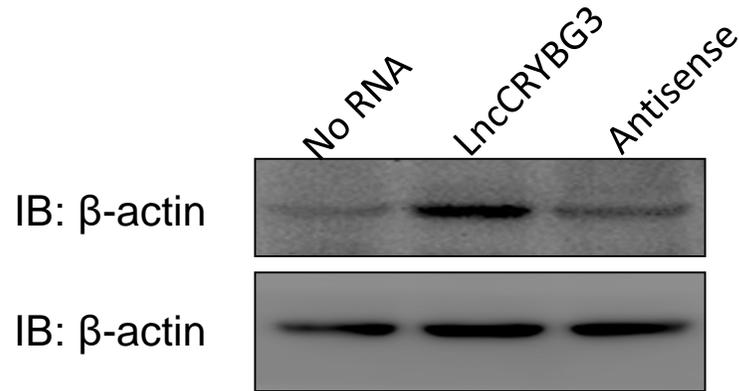
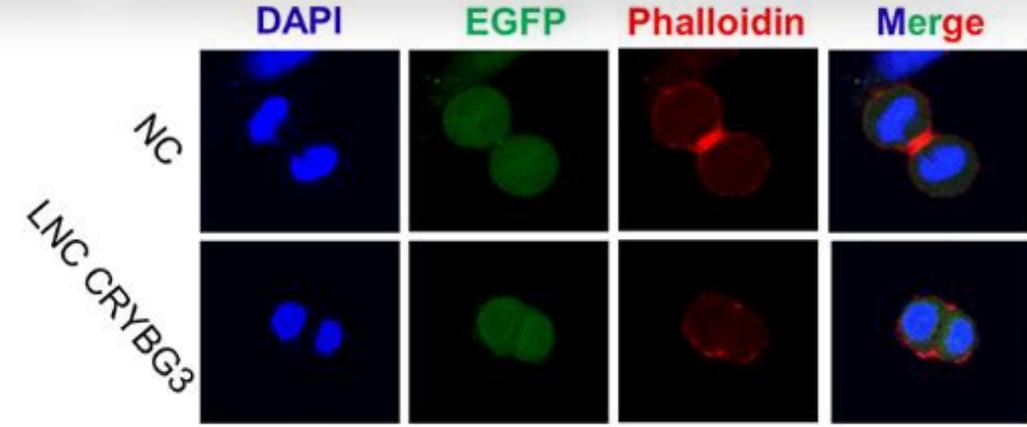
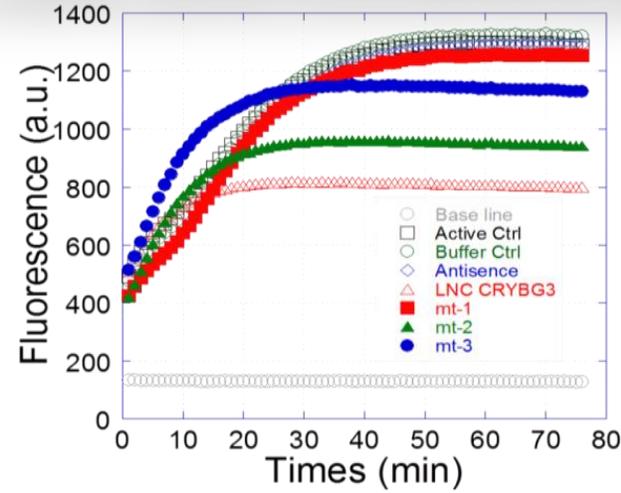
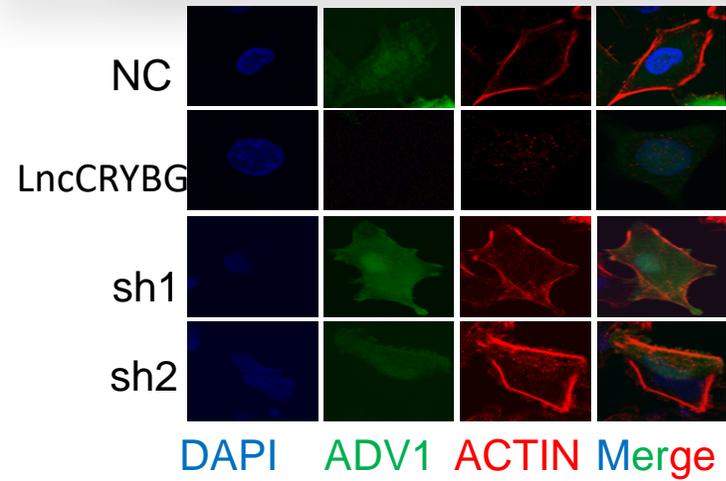
Eur J Physiol, 2016

Mechanisms of IR-induced carcinogenesis



➤ LncRNAs are also a key game-player in radiobiological effects.

Mechanisms of IR-induced carcinogenesis



NC

LNC CRYBG3

Pei *et al.* Cancer Res, 2018

➤ LncCRYBG3 directly binds to G-actin to block the assembly of microfilament.

22

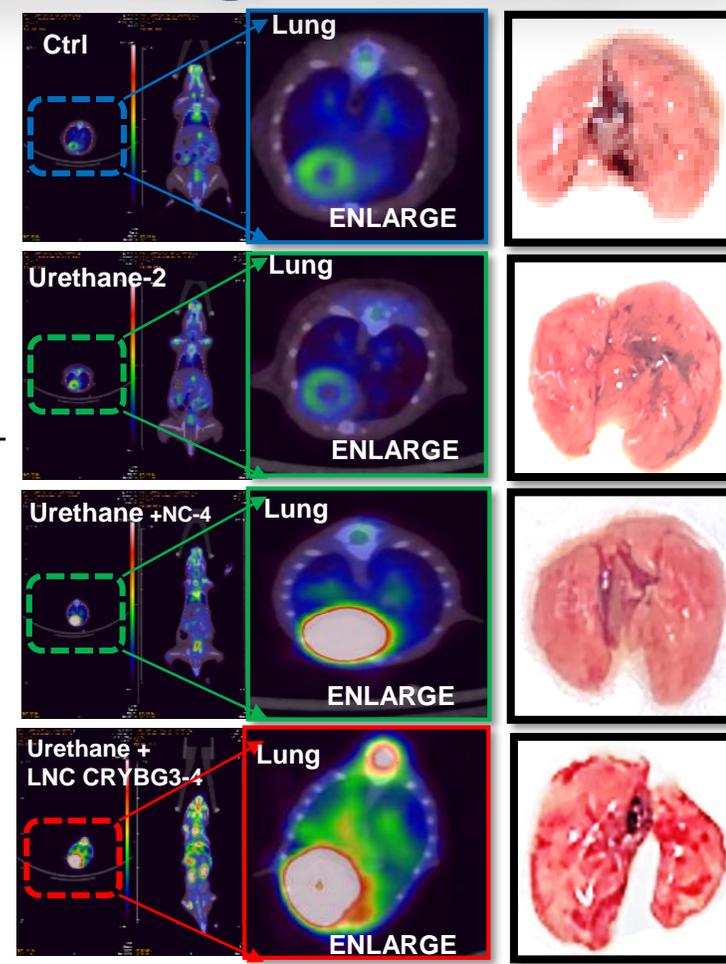
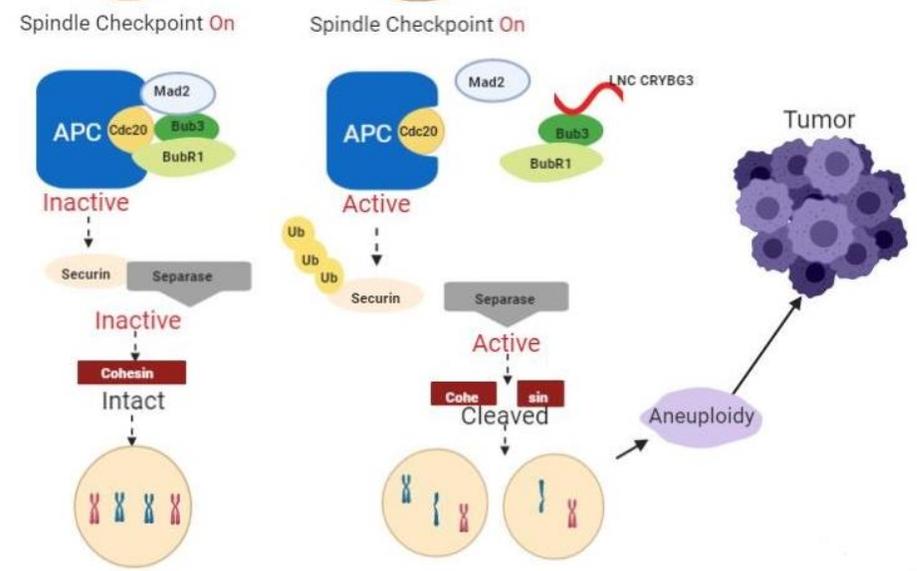
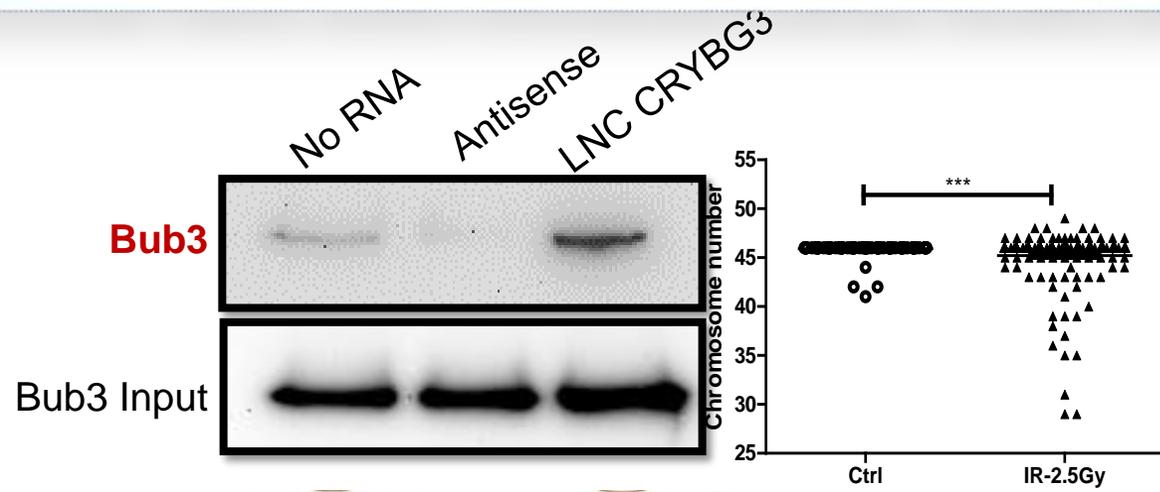
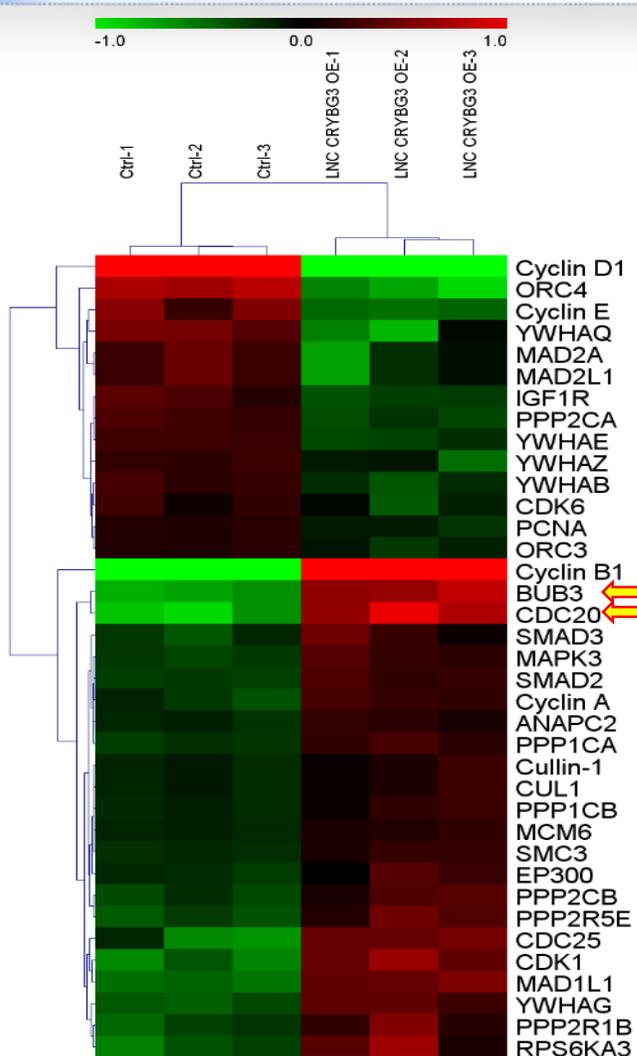


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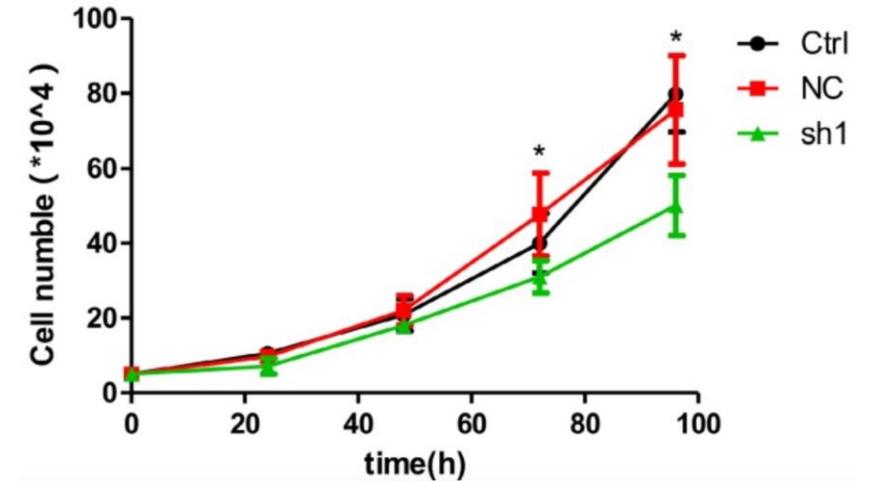
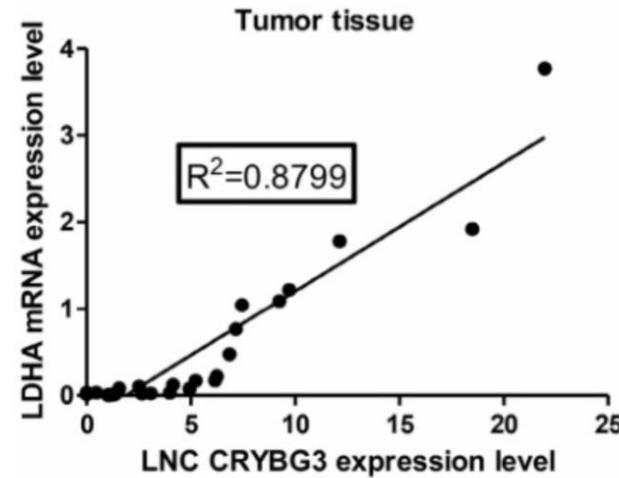
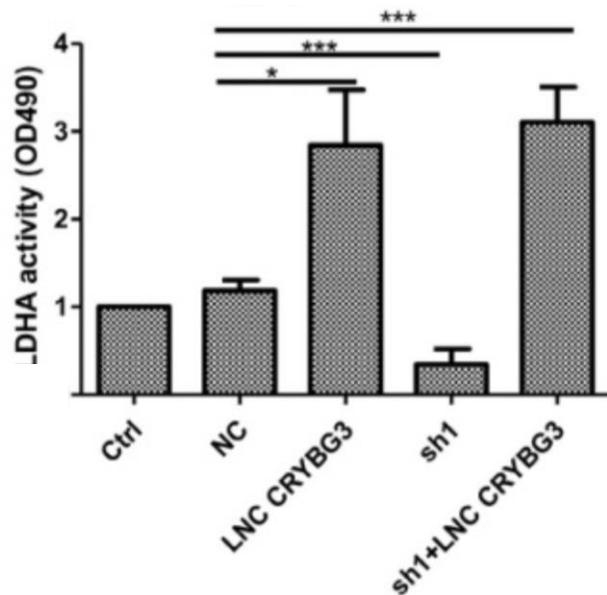
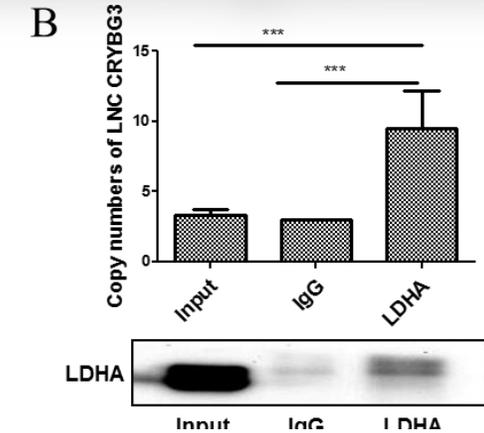
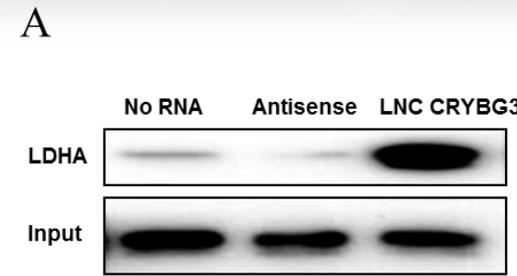
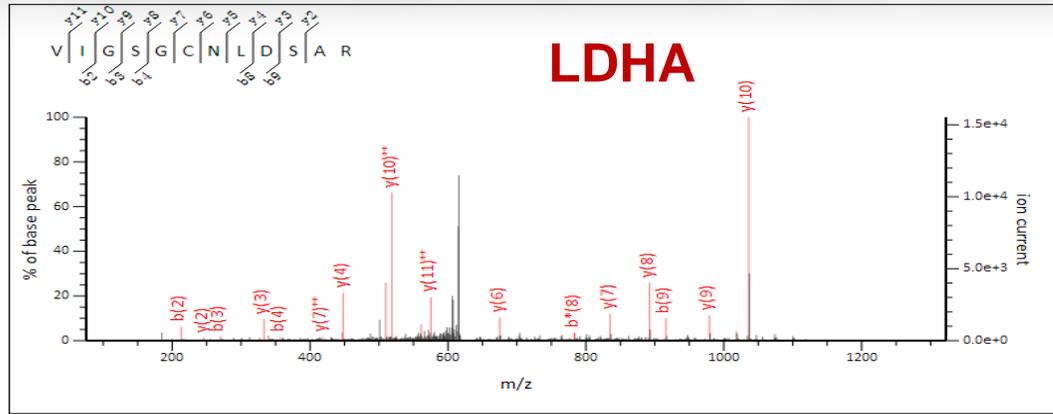
Mechanisms of IR-induced carcinogenesis



Guo et al. Under review

➤ LncCRYBG3 directly binds to Bub3 to activate APC/C complex immaturely.

Mechanisms of IR-induced carcinogenesis



Chen *et al.* J Cancer, 2018

➤ LncCRYBG3 directly binds to LDHA and activates it.



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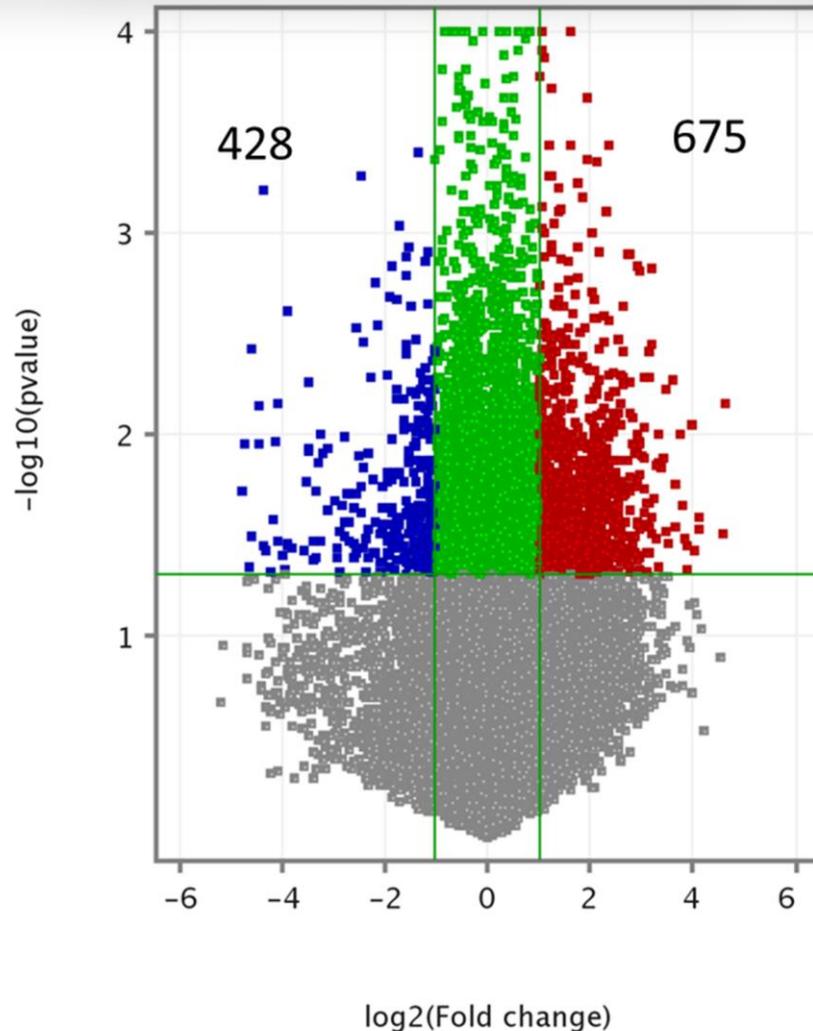
Mechanisms of IR-induced carcinogenesis

SCIENCE CHINA
Life Sciences



October 2021 Vol.64 No.10: 1602–1611
<https://doi.org/10.1007/s11427-020-1874-6>

•REVIEW•



AFAP1-AS1: a rising star among oncogenic long non-coding RNAs

Fang Xiong^{1,2,3}, Kunjie Zhu⁴, Su Deng¹, Hongbin Huang¹, Liting Yang², Zhaojian Gong⁵,
Lei Shi⁵, Yi He⁴, Yanyan Tang⁴, Qianjin Liao⁴, Jianjun Yu⁴, Xiaoling Li³, Yong Li⁶,
Guiyuan Li³, Zhaoyang Zeng³, Wei Xiong³, Shanshan Zhang^{2*} & Can Guo^{3*}

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Received August 26, 2020; accepted December 13, 2020; published online May 13, 2021

Xiong *et al.* *Gastroenterology*, 20s1

► Up-regulation of IncCRYBG3 alters the expression profile of lncRNAs.

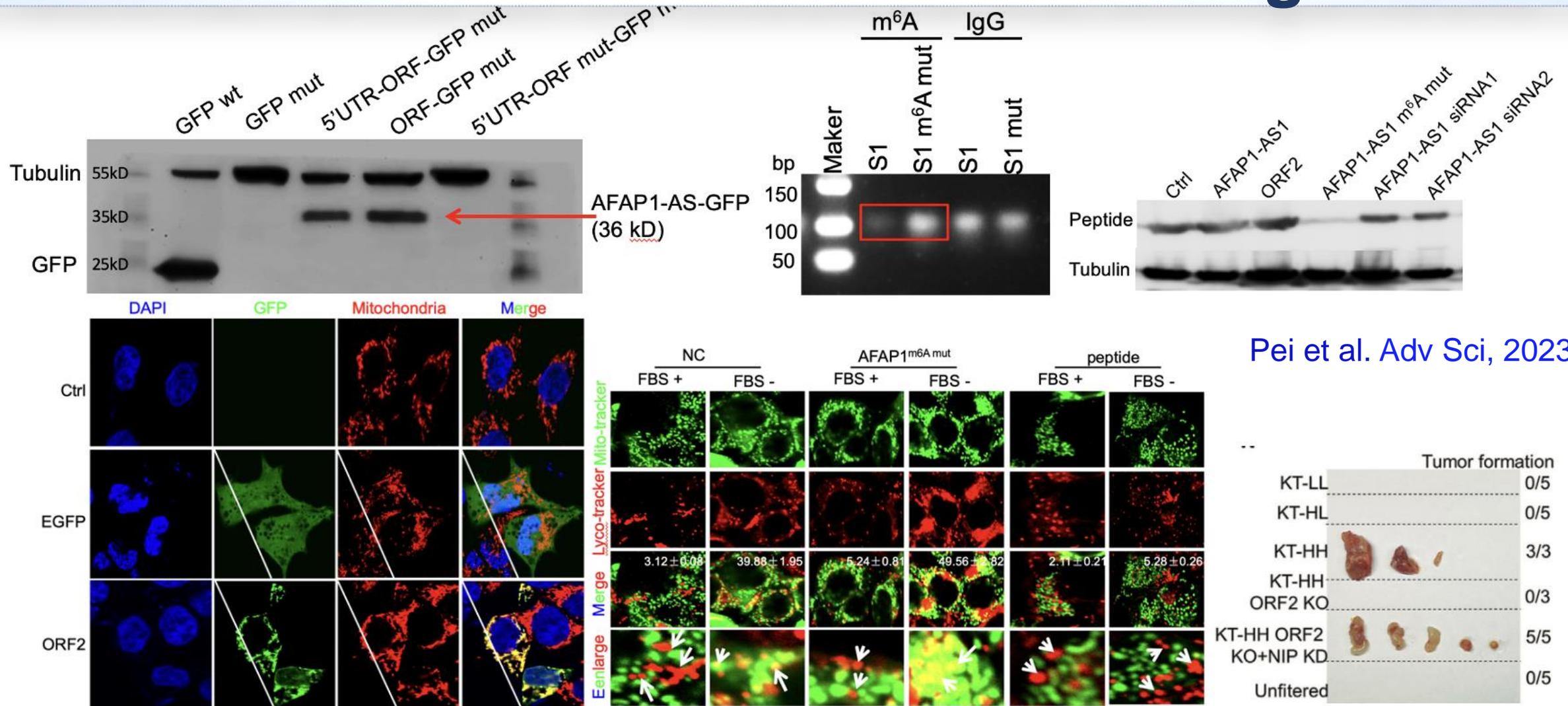


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Mechanisms of IR-induced carcinogenesis



Pei et al. Adv Sci, 2023

➤ It is not AFAP1-AS1 but its coded peptide promoting carcinogenesis.

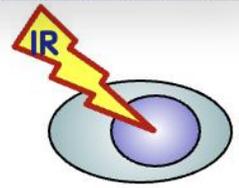


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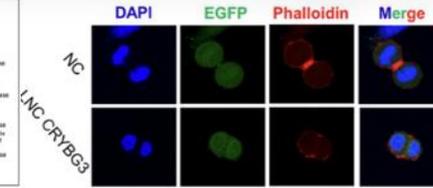
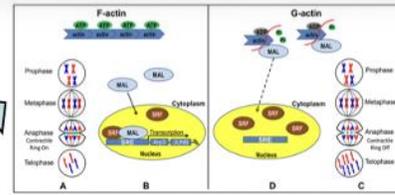


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Mechanisms of IR-induced carcinogenesis

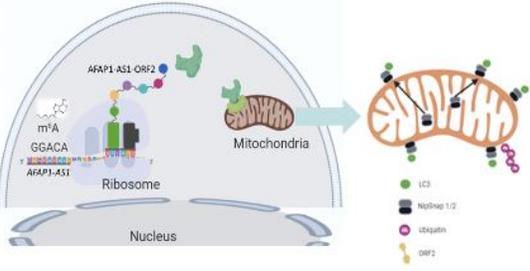


LNC CRYBG3表达

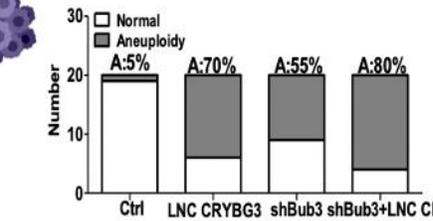
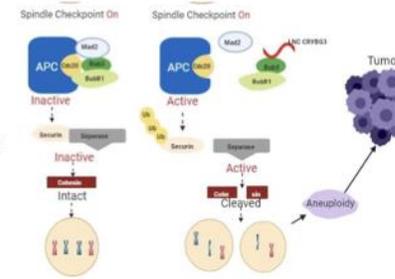
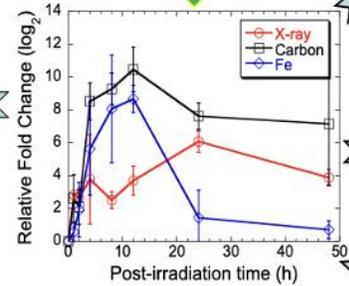


与G-actin 互作, 阻断微丝组装和胞质分裂。

Pei et al. Cancer Res, 2018

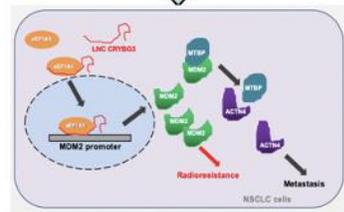


诱导LNC AFAP1-AS1, 后者表达ATMLP多肽, 抑制细胞自噬。
Pei et al. Adv Sci, 2023

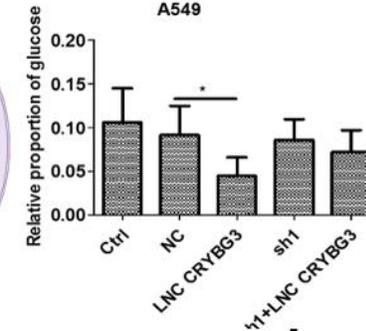
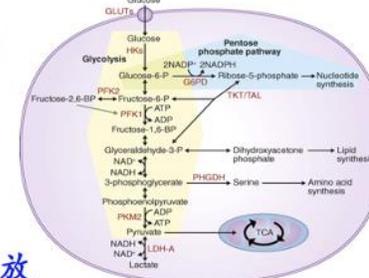


与Bub3互作, 干扰APC/C功能, 导致非整倍体发生。

Pei et al. Under Review



与eEF1A1互作, MDM2表达, 释放ACTN4促进转移。 Pei et al. Int J Mol Sci, 2021



与LDHA互作, 促进糖酵解。

Hu et al. J Cancer, 2018

Carcinogenesis

➤ One lncRNA leads to carcinogenesis by simultaneously targeting on multi-proteins.

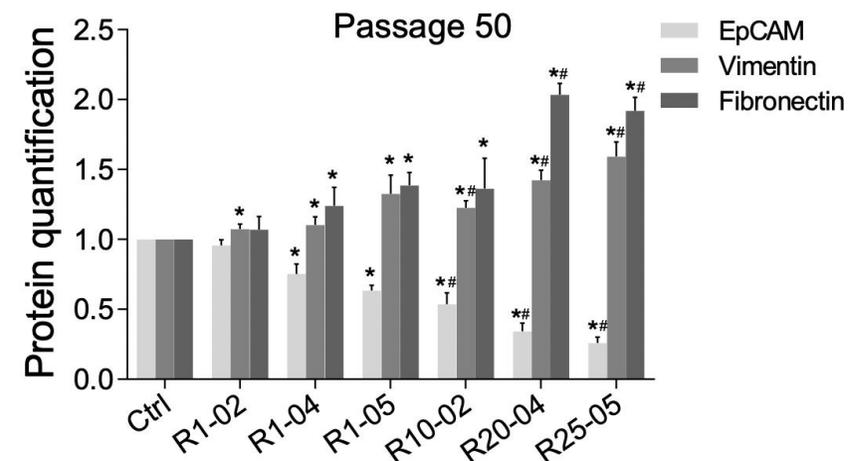
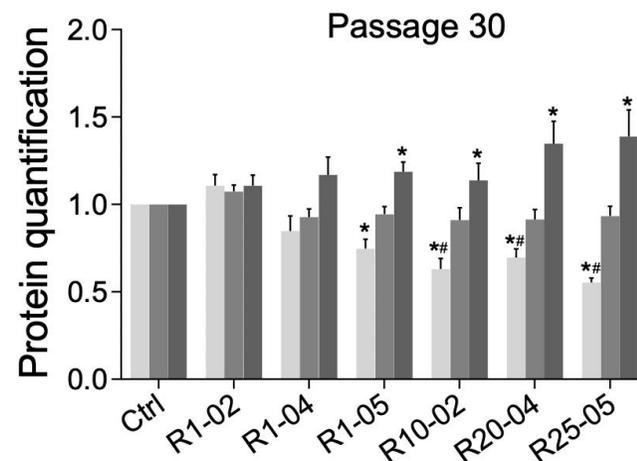
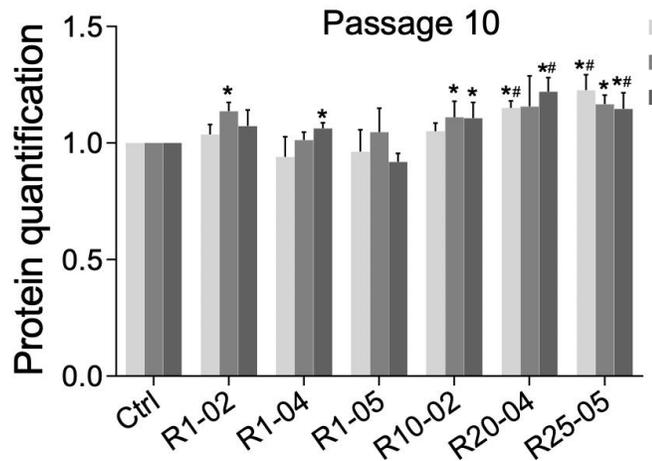
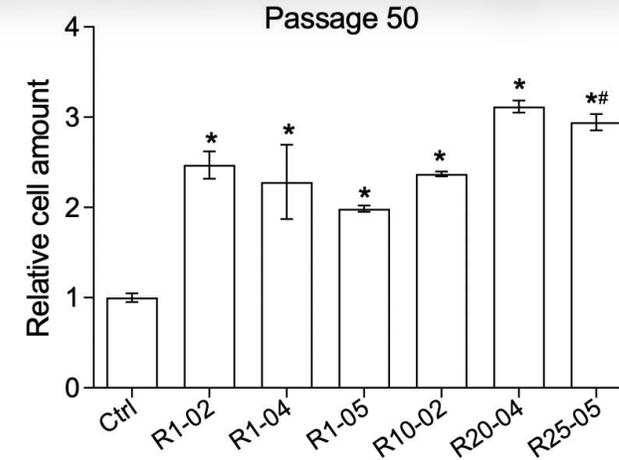
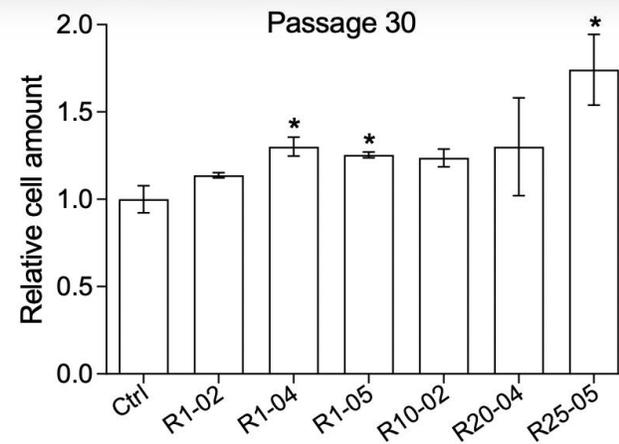
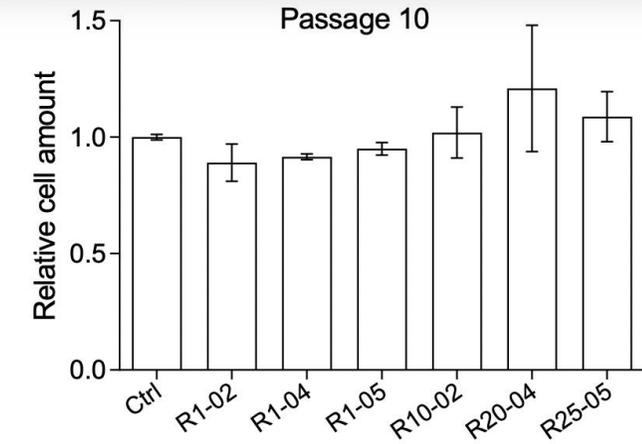


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Mechanisms of IR-induced carcinogenesis

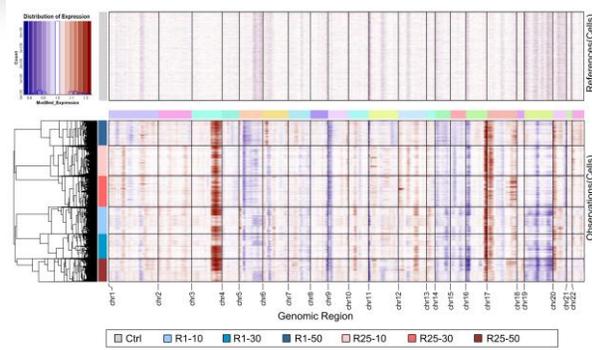


Li et al. Bri J Cancer, 2025

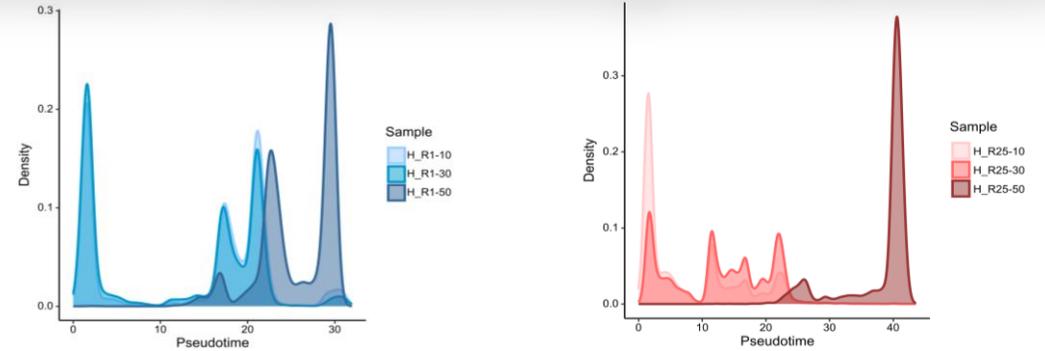
➤ Cellular evolution occurs in the proliferation following exposure.



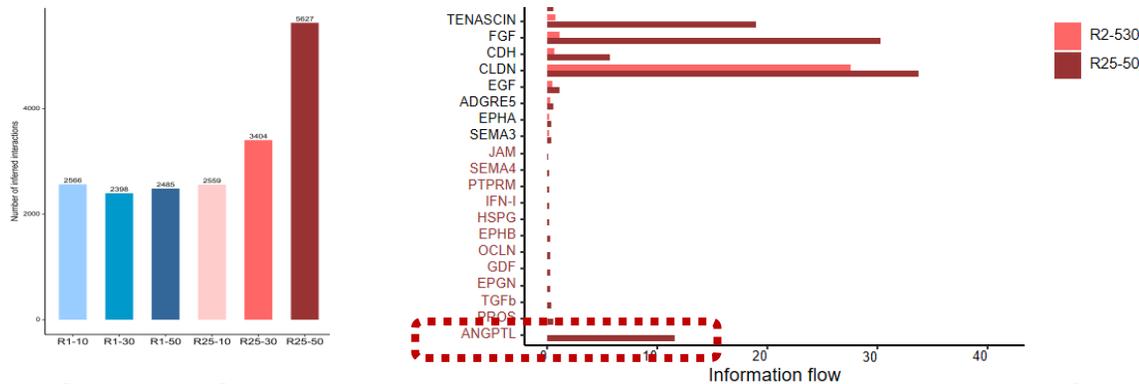
Mechanisms of IR-induced carcinogenesis



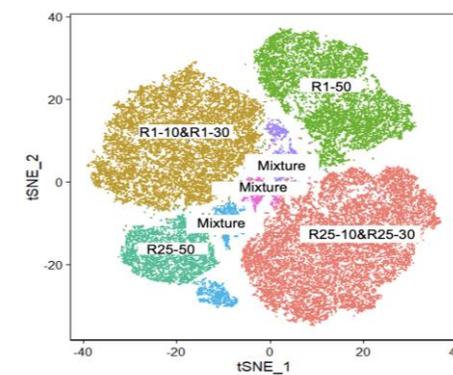
➤ Low dose-rate exposure raises higher malignancy.



➤ Carcinogenesis is a quantitative-to-qualitative process.



➤ Low dose-rate exposure increases the number of interacting ligands.



➤ Low dose-rate exposure shares no evolution route with acute one.

Li et al. Bri J Cancer, 2025 ³⁰



Summary

➤ **Biological effects:**

1. Low dose-rate HZE exposure does not increase cancer risk, which means those data of cancer risk obtained with acute exposure are applicable for risk assessment.
2. Microgravity enhances radiation carcinogenesis, which has to be considered in risk assessment.

➤ **Mechanisms:**

1. LNC CRYBG3 simultaneously regulates multiple cellular processes by targeting on several proteins and even lncRNAs, therefore it might be used as a novel target for cancer prevention.
2. Tumor evolution is a quantitative-to-qualitative process and its direction is dependent on exposure method. Key ligands during tumor evolution might be applicable for cancer prevention.

Thanks for your attention



Tom K. Hei, Guenther Reitz, Francis Cucinotta, Chuanyuan Li.....
Hailong Pei, Weiwei Pei, Wentao Hu, Ningang Liu, Caiyong Ye.....
Yingxian Li, Tao Zhang, Mei Hong, Biao Chen, Shizhong An.....



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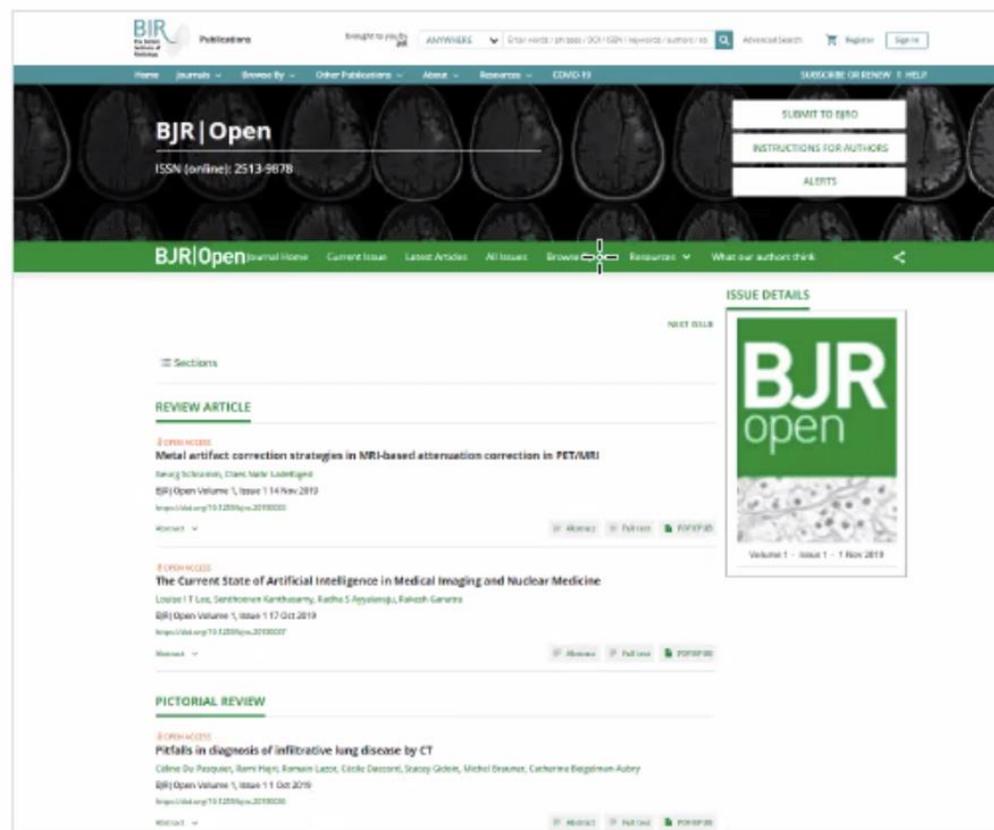
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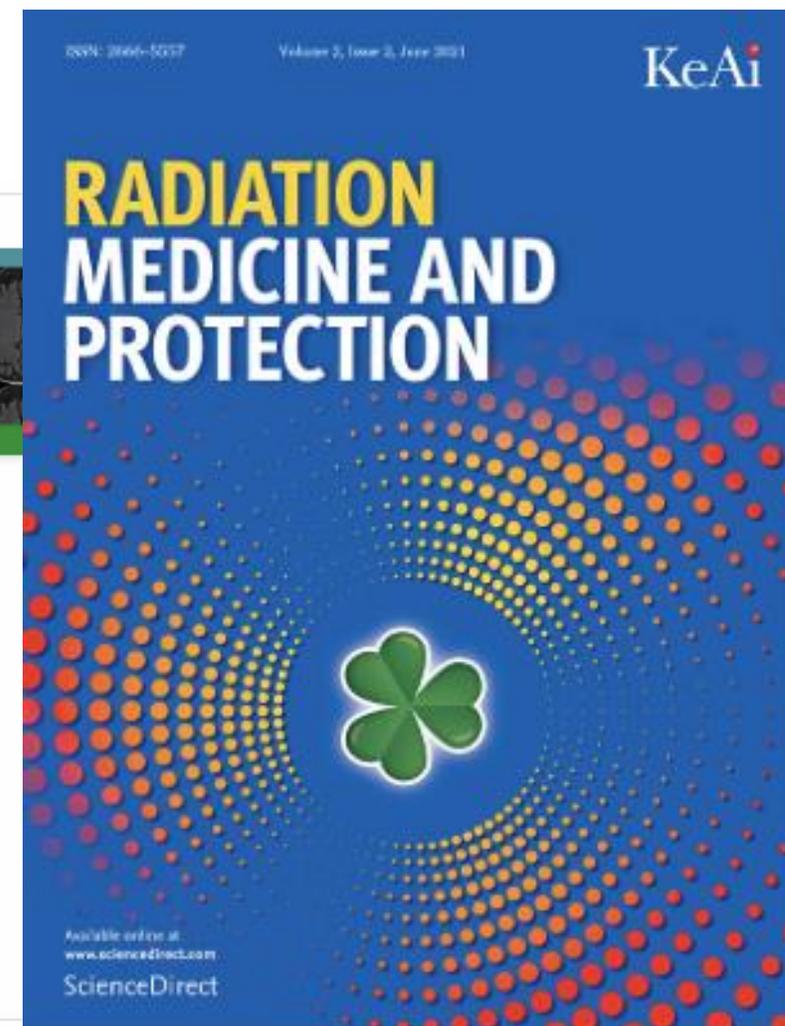
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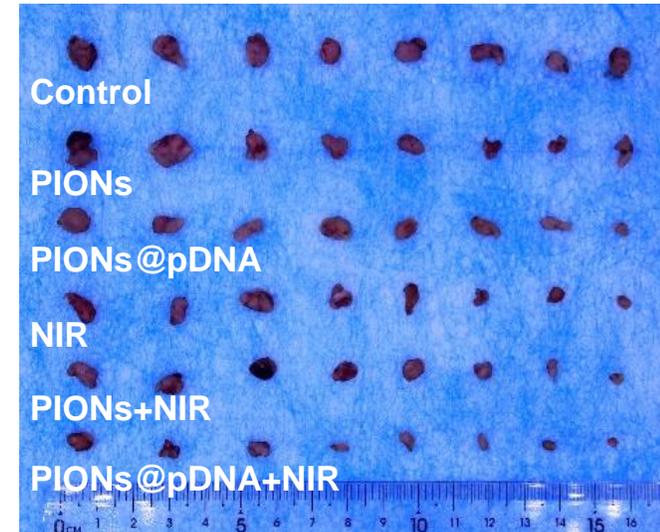
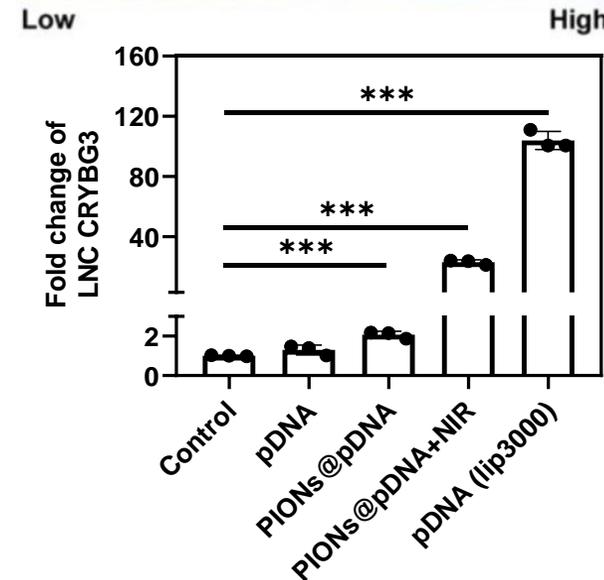
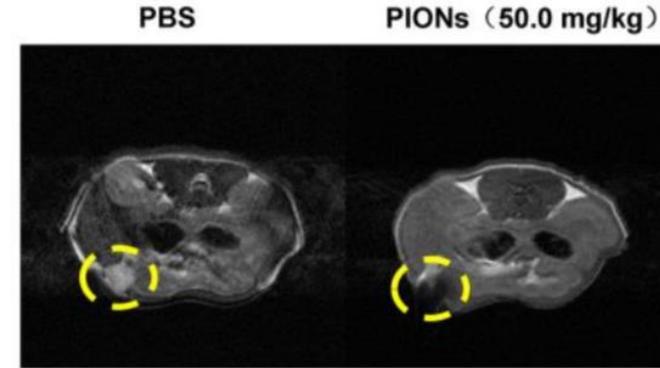
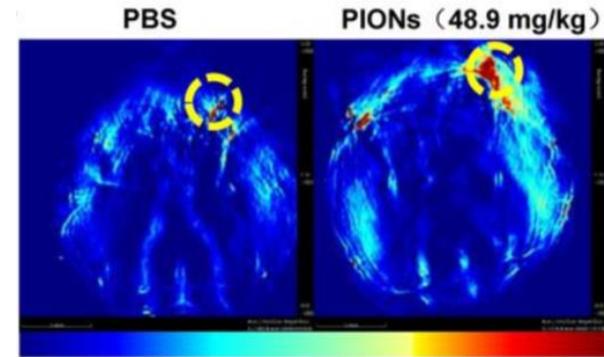
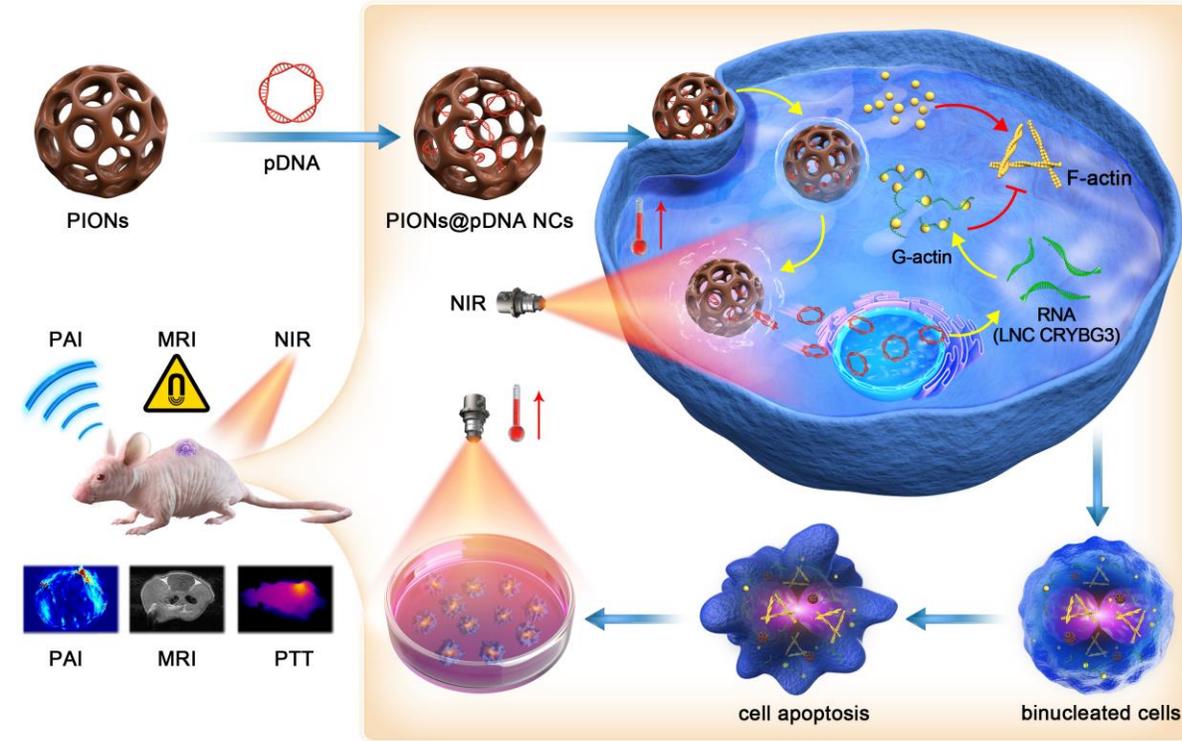


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Summary

Photoacoustic imaging

MRI



Huang *et al*, Bioactive Materials, 2021

➤ LncCRYBG3 gene therapy and photothermal therapy using mesoporous nanoagents

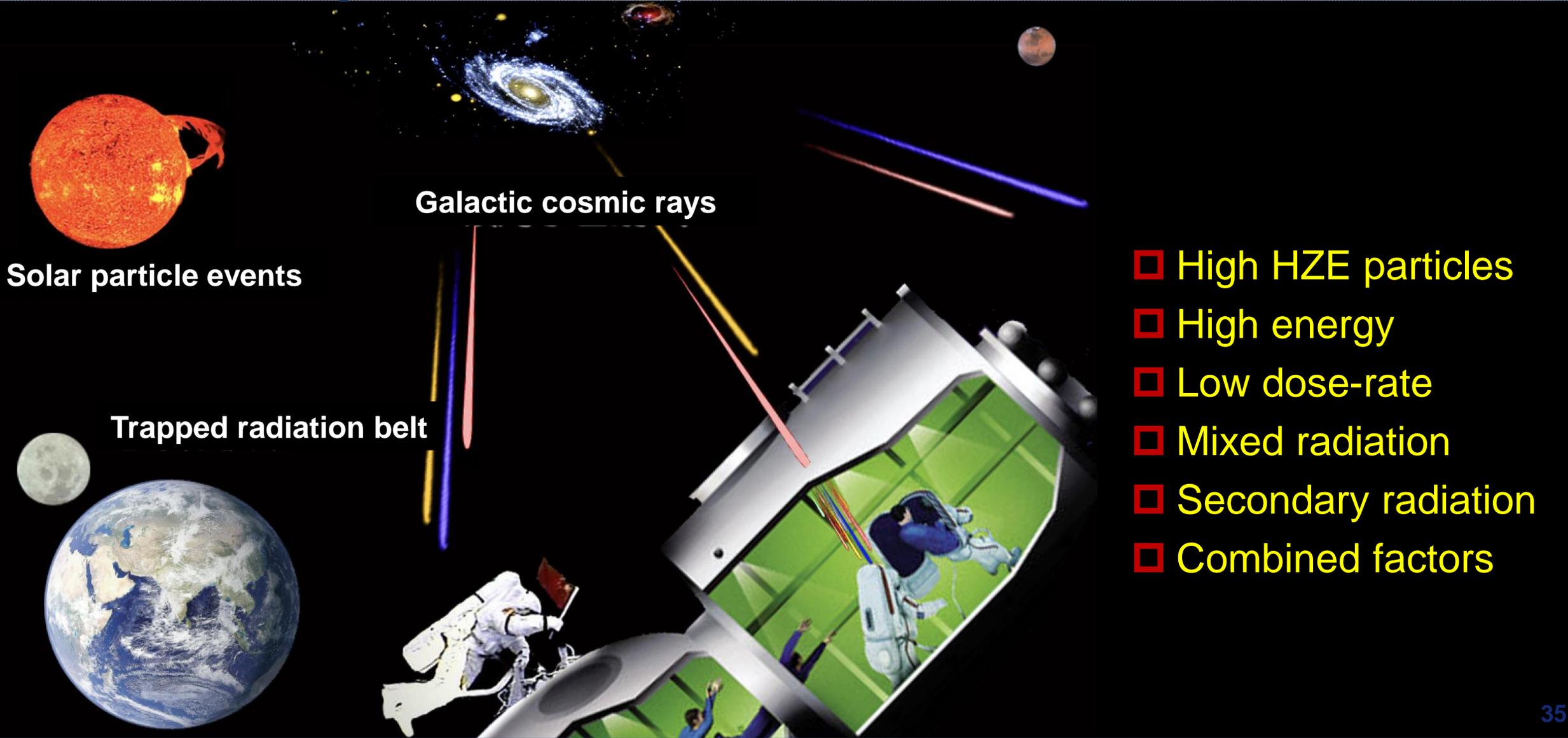


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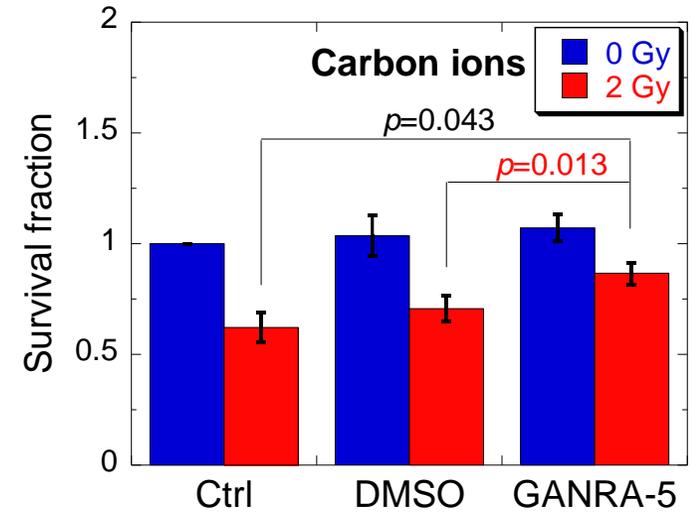
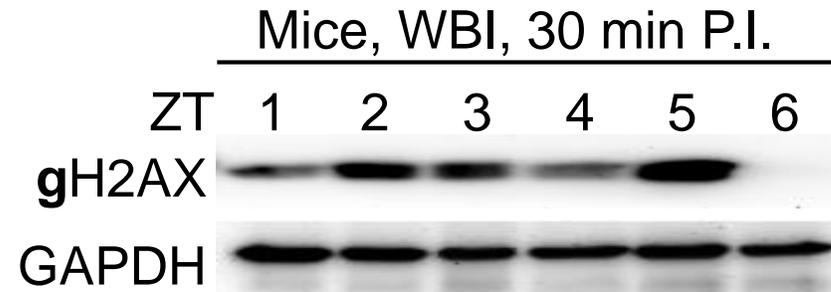
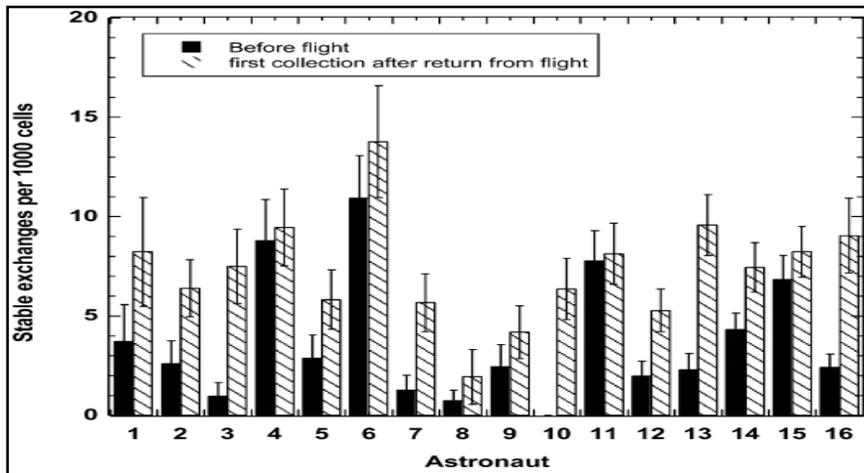
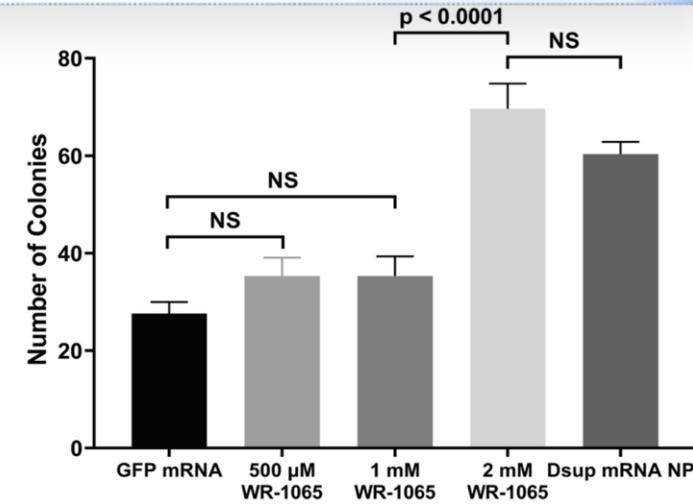
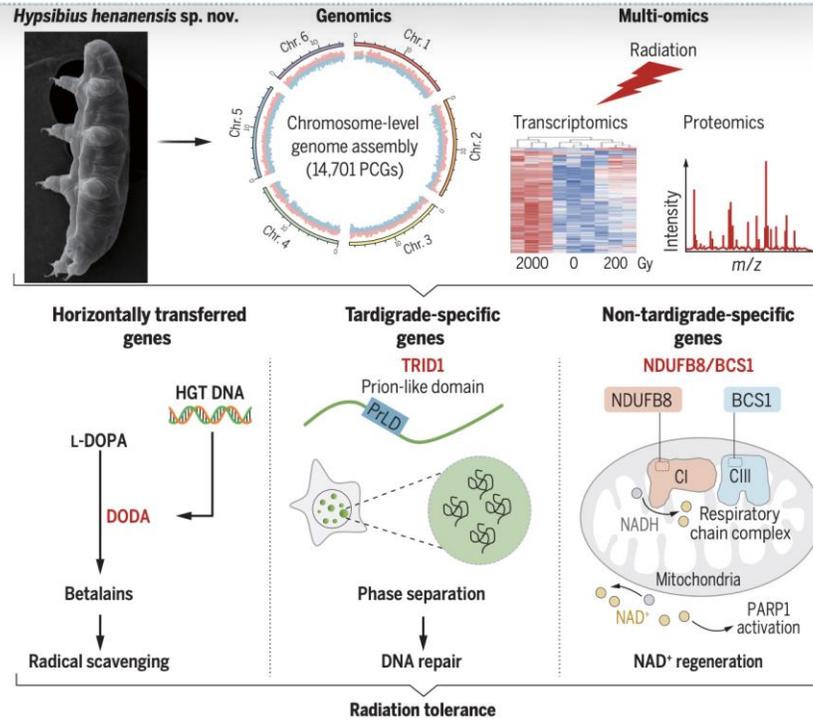
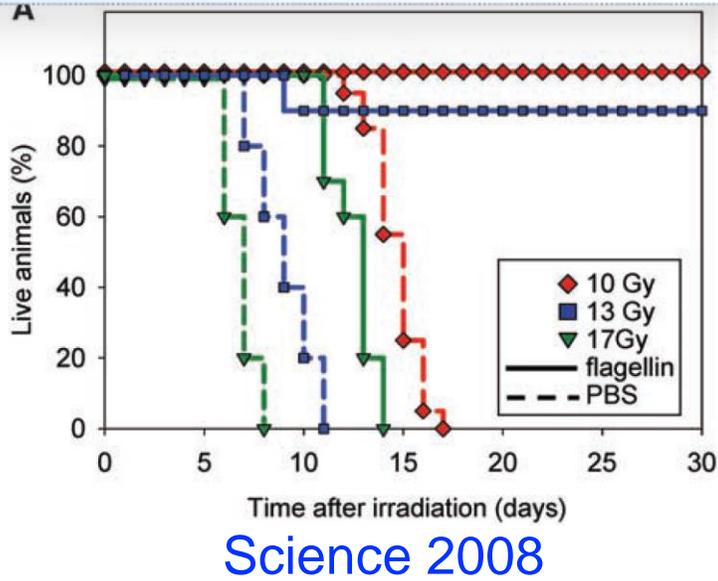


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Space radiation environment



Countermeasures

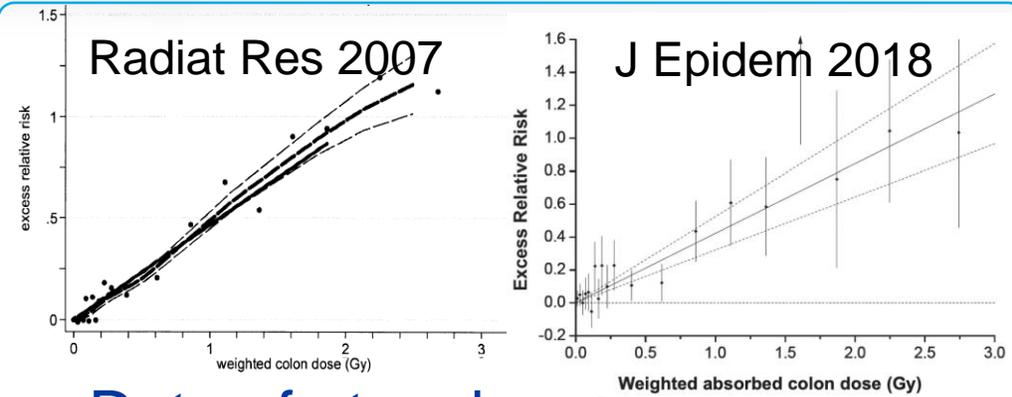


Carcinogenesis of Space radiation

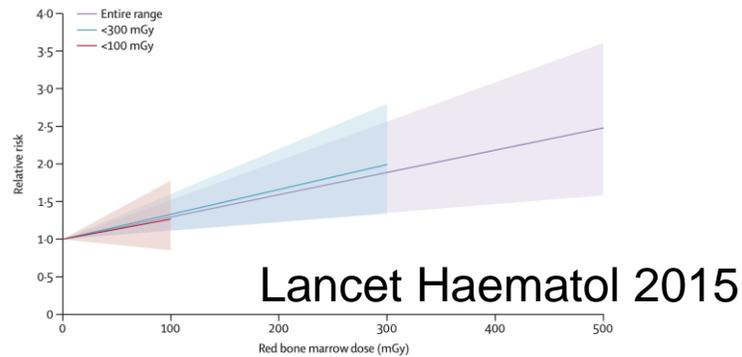
No. of participants	No. of cancer	Incidence (%)
312 astronauts	14	4.5
928 counterparts	26	2.8

Radiat Res 2003

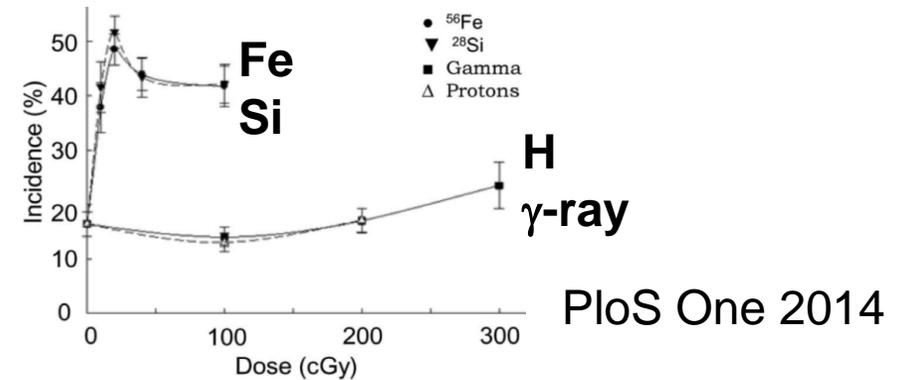
NASA-LSAH:
Limited scale of cohort



Data of atom bomb survivors:
Acute exposure



Data of occupational worker:
Different type of radiation

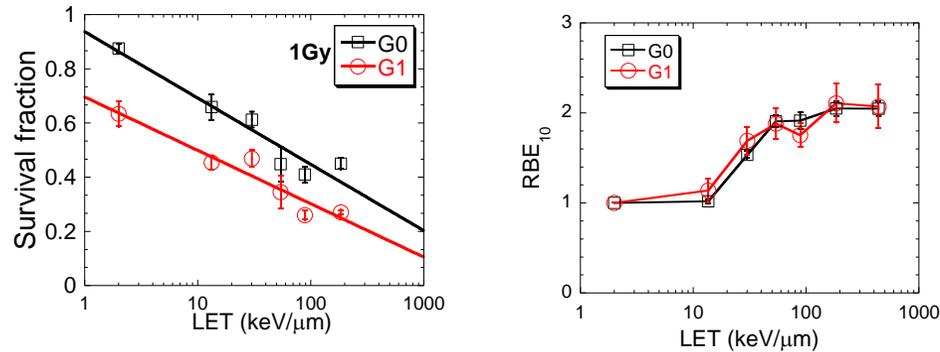


In vivo experimental data:
Not human being



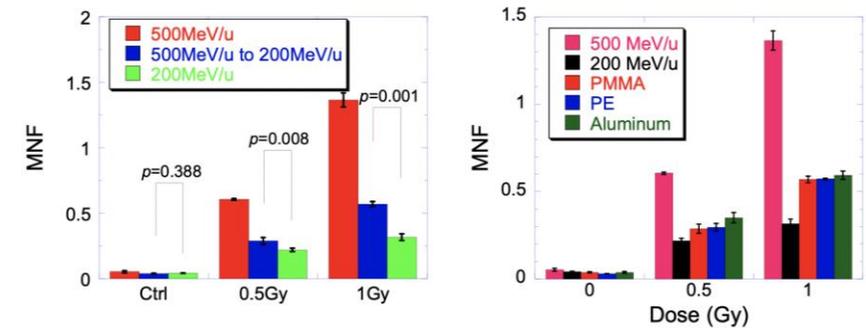
Carcinogenesis of Space radiation

Ding *et al.* Adv Space Res, 2013



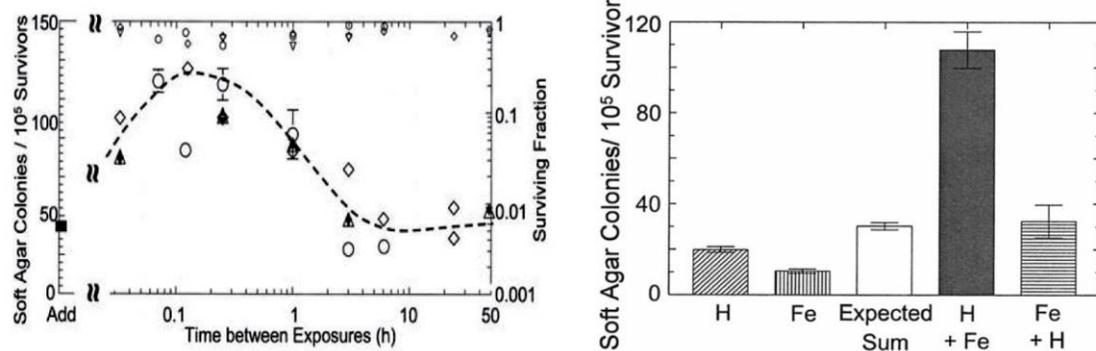
Effects of HZE particles

Hu *et al.* J Radiat Res, 2013



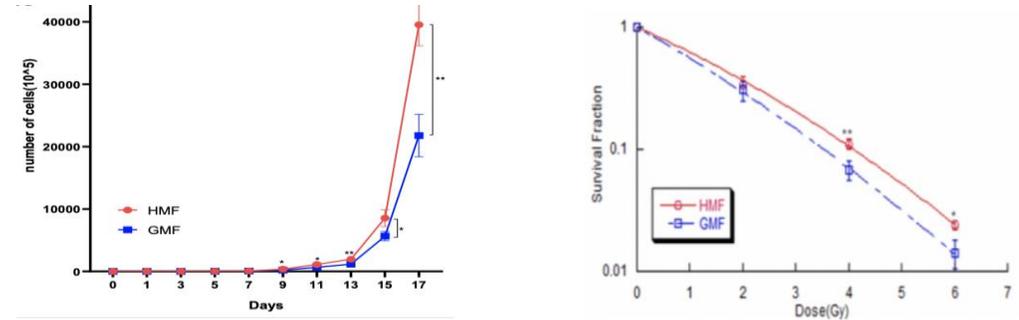
Effects of secondary radiation

Zhou *et al.* Radiat Res, 2006



Effects of mixed exposure

Under review



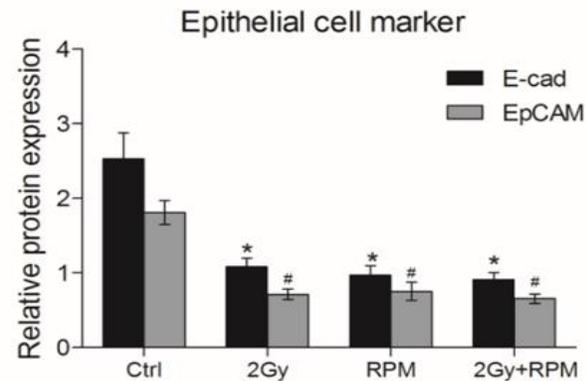
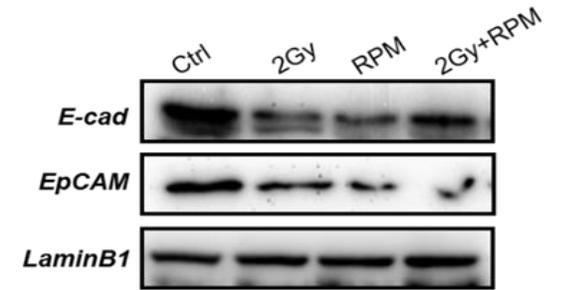
Impact of hypo-magnetic field on radio-effects

Carcinogenesis of Space radiation

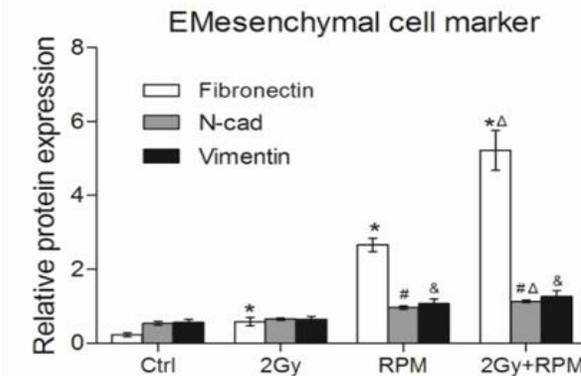
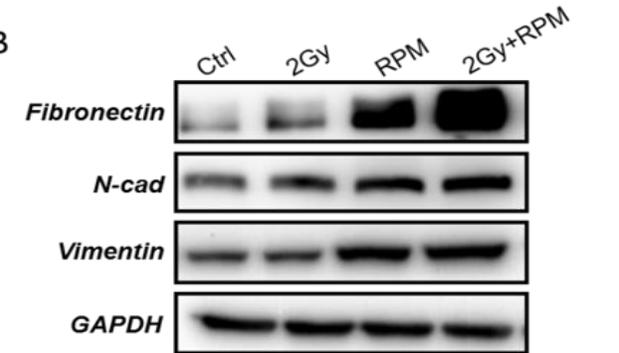
Microgravity

Cell models	Treatments	Effects	Ref.
human fibroblast 1BR-hTERT	X/C (0.5, 1.5 Gy) 3D clinostat (24 h)	increased CA	Hada 2019
human lymphocytes	X (1.5 Gy) cuvette clinostat (2 h)	increased CA	Mosesso 2001
human peripheral blood lymphocytes	γ (5 Gy) RWV (0.5, 2, 6, 24 h)	decreased DNA repair	Mognato 2009
human lymphoblastoid TK6	γ (1, 2, 4 Gy) RWV (24 h)	increased HPRT mutation and MNF	Canova 2005
human peripheral blood lymphocytes	X/ γ (1, 2 Gy) RWV (24 h)	increased HPRT mutation	Mognato 2005
human fibroblasts 1BR-hTERT	X/C (1 Gy) 3D clinostat (48 h)	DNA damage and failure of cell cycle block	Ikeda 2019

A



B

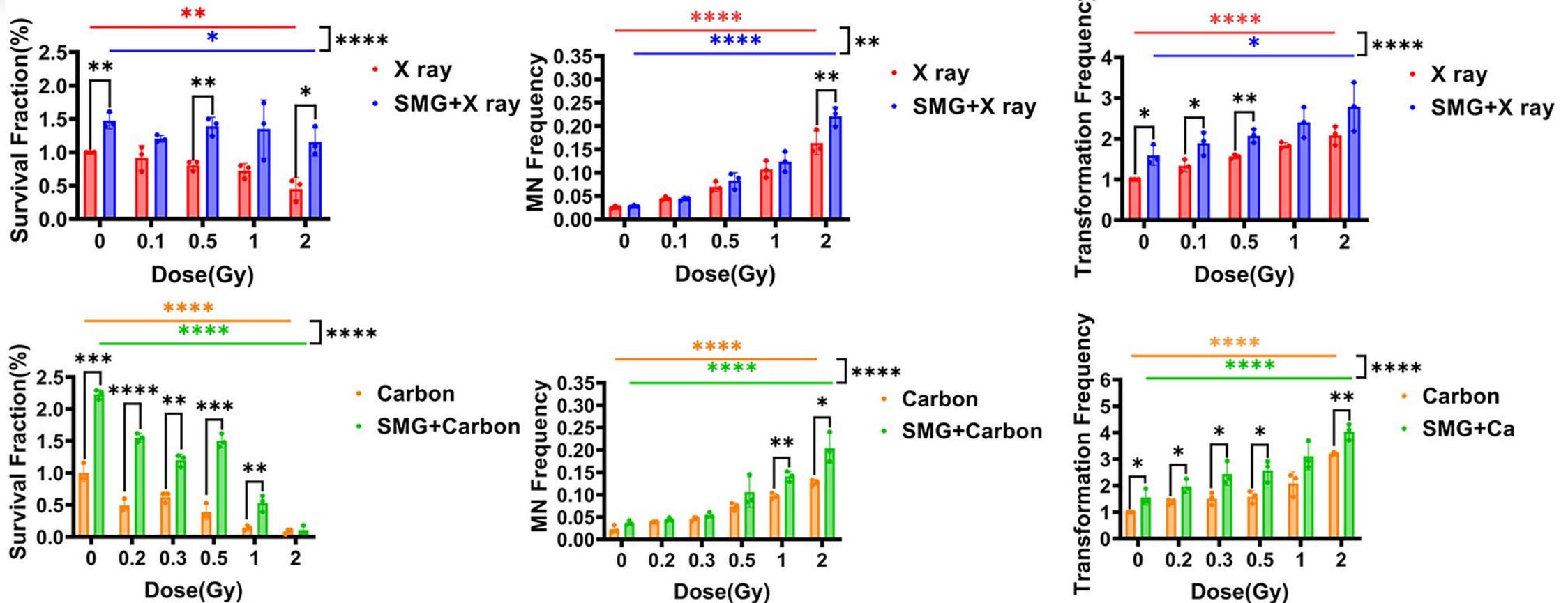


Under review

Microgravity and radiation have synergistic effects on the induction of EMT.

Carcinogenesis of Space radiation

Microgravity



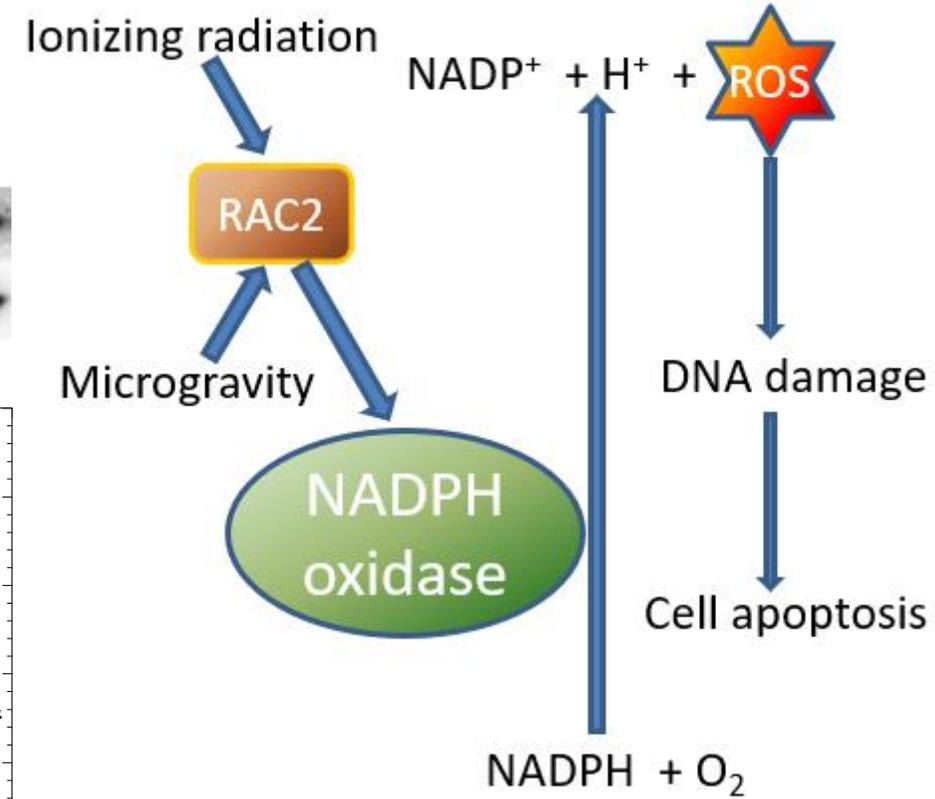
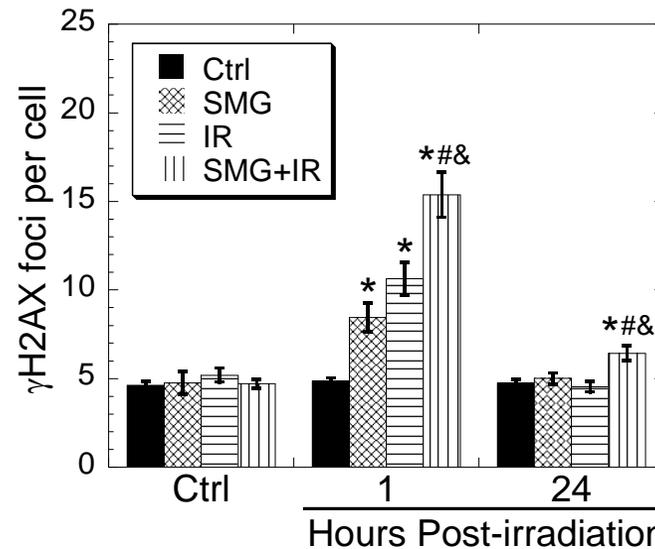
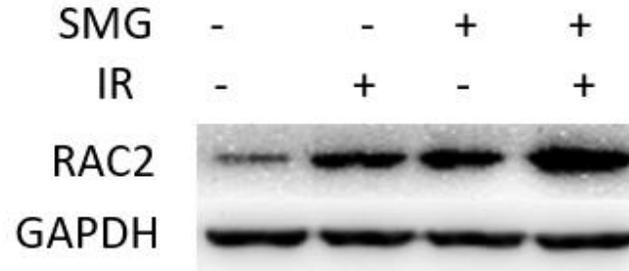
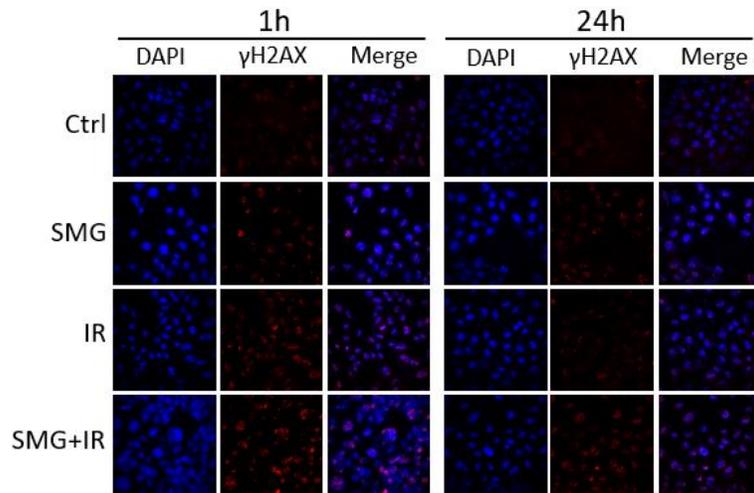
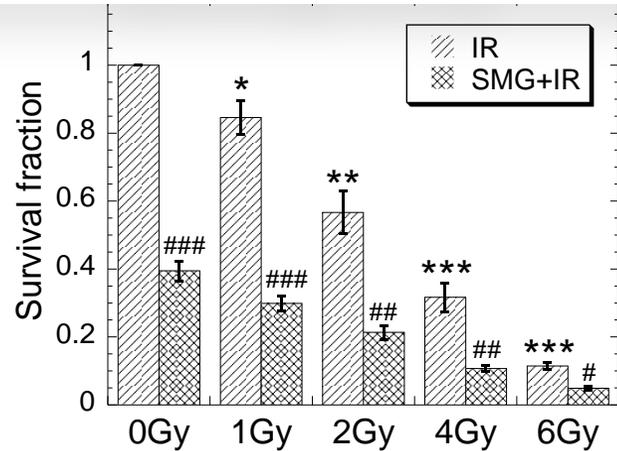
Ding *et al.* NPJ Microgravity, 2025

➤ Simulated microgravity enhances radiation-induced carcinogenesis.



Carcinogenesis of Space radiation

Microgravity



Tan *et al.* NPJ Microgravity, 2020

➤ Simulated microgravity enhances IR-induced DNA damage and cell death via RAC2.

