Investigating the effects of microgravity and radiation on the musculoskeletal system of astronauts using Magnetic Resonance Imaging

Dr Niveta Ramakrishnan MB BCh BAO(NUI, RCSI) LRCP SI

Hypothesis

To **measure** or **monitor non-invasively** at regular intervals with a compact MR System with regards to the **three chief health concerns of astronauts** namely

1. Loss in Bone Density
2. Loss in Muscle Mass and Tone
3. Damage to Tissues

Why? Due to the **microgravity** and **background radiation** exposure during **long duration of space travel(LDST).**

SUPERVISOR

Dr J Thomas Vaughan, Jr. Ph.D, Professor
Director of Columbia Magnetic Resonance Research Centre(CMRRC)
School of Engineering and Applied Sciences;
Biomedical Engineering, Applied Physics and Applied Mathematics,
College of Physicians and Surgeons; Radiology
Mortimer B Zuckerman Mind, Brain, Behavior Institute;
Member, PI, MR Platform Director

Columbia University
New York

INVESTIGATION

Effects of microgravity and radiation on the Musculoskeletal System of astronauts using Magnetic Resonance Imaging

Introduction

- Developed the interest to understand the degeneration of the musculoskeletal system of the Astronauts during their space exploration.
- Interest started from the year 2012 during my small stint as a school student to develop the **Mars Rover at Johnson Space Centre, Houston.**
- Persistently sent messages to NASA and related space project universities in USA by effective use of Social media like **Linked In.**
- Finally, efforts were paid off and got the Opportunity to work with **Dr. Thomas Vaughan of Columbia University.**

Hypothesis

To **Measure** or **Monitor Non-invasively** at regular intervals with a Compact MR System with regards to the **three chief health concerns of astronauts** namely **Loss in Bone, Loss in Muscle Mass and Tone, Tissue Damage due to the background radiation exposure during long duration of space travel**

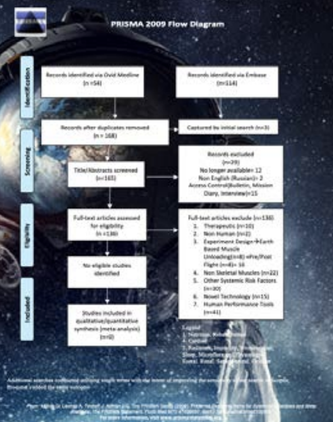
On-Orbit hardware at ISS Medical Post

(Present Status)

- Actiwatch Spectrum system
- Cerebral cochlear fluid pressure analyzer(CCFP)
- Distortion product otoacoustic emissions device(DPOAE)
- Holter monitor
- Human research facilitits 1 and 2(HRF 1&2)
- On orbit laptops
- Pulmonary function system(PFS)- Pulmonary function module(PFM), photoacoustic analyzer module(PAM), Gas delivery system
- Refrigerated centrifuge(RC)
- Space linear acceleration mass measurement device(SLAMMED)
- **Human research facility ultrasound**
- Consumable Hardware-HRF supply kits(Purple and green), Blood collection, saliva collection, urine collection
- Experiment specific hardware-fine motor skills, fluid shifts, lighting effects, microbiome

Methods

- **Scopus**
- **Proquest**
- **Digital Encyclopedia of Applied Physics**
- **NASA Research Roadmap**

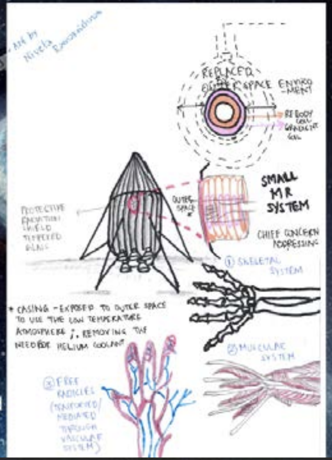


Findings from the Existing Literature

1. Protective Spacesuit equipment known as **Penguin Suit** is used to reduce the threats arising outside the magnetosphere which exposes the human body to radiation.
2. **Ground based Model** to quantify POST HIGH linear energy transfer exposure to extra vehicular activity using **Blood samples**.
3. **Advance Simulated Training at Buoyancy Labs** is not sufficiently preparing the Astronauts to adapt on exposure to the harsh environment of the space mission. This causes irreversible damage to the Musculpskeletal System.
4. Findings from **"Advances in Space Technology"** by the NSBRI team highlights the **bone loss per month as 1-1.6%** compared to **0.8-1.6% per year in POST Menopausal women** and **6-10% muscle wasting in short duration to >10% Long duration space travel**. They are the Pioneers in devising new technology such as Neutron Spectrometer and the time of flight hydrogen mass spectrometer to assess flight radiation and critical Biomarkers identified before through Ground based analysis of urine samples of POST flight Astronauts.

Proposal

- **A compact, space ready, high-field >5T MRI unit**
- Superconducting Magnet positioned in the Ultra Low temperature in Outer space
- Suitably designed penetration chamber within the space capsule
- Replacing the bulkiest cryogenic cooling system
- Baseline of the rate of change of human physiology, in-flight, real time data
- Transmitted to earth via satellite
- Data analysation and interpretation by ground based technicians



Summary

Parameters	Ultrasound	Dual Energy X-Ray Absortiometry	MRI
Non-Invasive	Yes	Yes	Yes
Resolution	Low	High	High
Ionizing (Electromagnetic Spectrum)	No	Yes(10^{-8}-10^{-11})	No(10^{3}-10^{-1})

- The comparison of **existing in-flight Ultrasound** to our **proposed small MR system**, where MR excels over Ultrasound due to its **high resolution and minimised rate of error in acquiring quality images**.
- The preliminary findings of metric data observed among participants comparing Ultrasound to Dual energy x-ray absorptiometry(DXA) reported in the NASA Task Book Maps.
- Therefore, in spite of DXA and MR having excellent resolution, **MR** prevails over others due to added benefits of its **non-ionising, non-invasive** parameter. The rationale in choosing one imaging modality over another can be accounted for from simply noticing where they are in the extreme ends of the electromagnetic spectrum, the x-ray ionising wavelength at 10^{-8}–10^{-11} and MR radiofrequency waves non-ionising wavelength at 10^{3}-10^{-1}. The human body can be assessed at various levels of structural organisations such as at a molecular, cellular, organ and organ systems using

Conclusion

A Feasable Payload, Biomedical Engineered Compact MRI Design will formulate therapeutic countermeasure in the form of nutrition, exercises and pharmacologically as we lay the foundations of medical advancement for the Astronuats longer duration space travel.

What's Next?

- Will be submitting and applying for **NASA Nspires Grant** for further advancement of research, experiments and feasibility of Compact MRI Unit in International Space Station.
- Will be part of the **Bi-monthly Review meeting** at Columbia University Mortimer B. Zuckerman Mind Brain Research Institute through Video Conferencing along with **Ms.Monica Ramakrishnan**, 1st Year RCSI Medical Student.
- Will be sharing the information to understand the possibilities of getting the **Grant from Irish American Collaboration-European Space Agency**.

Key Learning

- Opportunity to work independently
- Literature Review
- MR Level II Safety Training
- Grant Proposal Writing
- Designing Novel Technology
- Research Presentation at weekly lab meetings

Support Team and Advisors

1) Ms.Kathleen Durkin – MR Research Administrator, Columbia University.

2) Mr.John Usseglio, MPH, Informationist, Augustus C. Long Health Sciences Library Columbia University Irving Medical Center.

3) Mr.Tavis Allison, Director of Grant Development, Columbia University Irving Medical Center.

4) Dr.Wei Shen MD, MPH, Assistant Professor of Nutritional Pediatrics, Department of Pediatrics and Institute of Human Nutrition College of Physicians & Surgeons, Columbia University Director, Image Analysis Laboratory, Obesity Research Center.

5) Dr.Gopalan Raghavan, Research Scientist, Quantum Information, Quantum Cryptography and Optical Properties at Department of Atomic Energy

6) Dr.Sridhar S. Nambi, MD, Director of Endocrinology-Diabetes and Metabolism, Internal Medicine, St.Barnabas Medical Center

Let me take you on a visual yet enthralling journey through novel space missions as we proceed to explore mars and beyond…

What’s happening right now?

EARTH:

Simulated spaceflight hazards in Ground Analogs – envihab(European Space Agency; Artificial Gravity Bed Rest – head-down tilt position), NEK/SIRIUS(Russia; Closed Habitat – Isolation and Confinement), HERA, Space Radiation Lab

LOW EARTH ORBIT:

International Space Station – A unique testbed to study microgravity and environment hazards, with varying mission durations

LUNAR MISSIONS:

Decreasing Earth-dependence around and on the lunar surface. Provides insight into deep space radiation, behavioural health, and gravity transitions.

What has happened? And why is there a need for novel approaches now?

Let’s walk through time to find answers

A) Where we are at?

B) Where we are heading towards?

Timeline

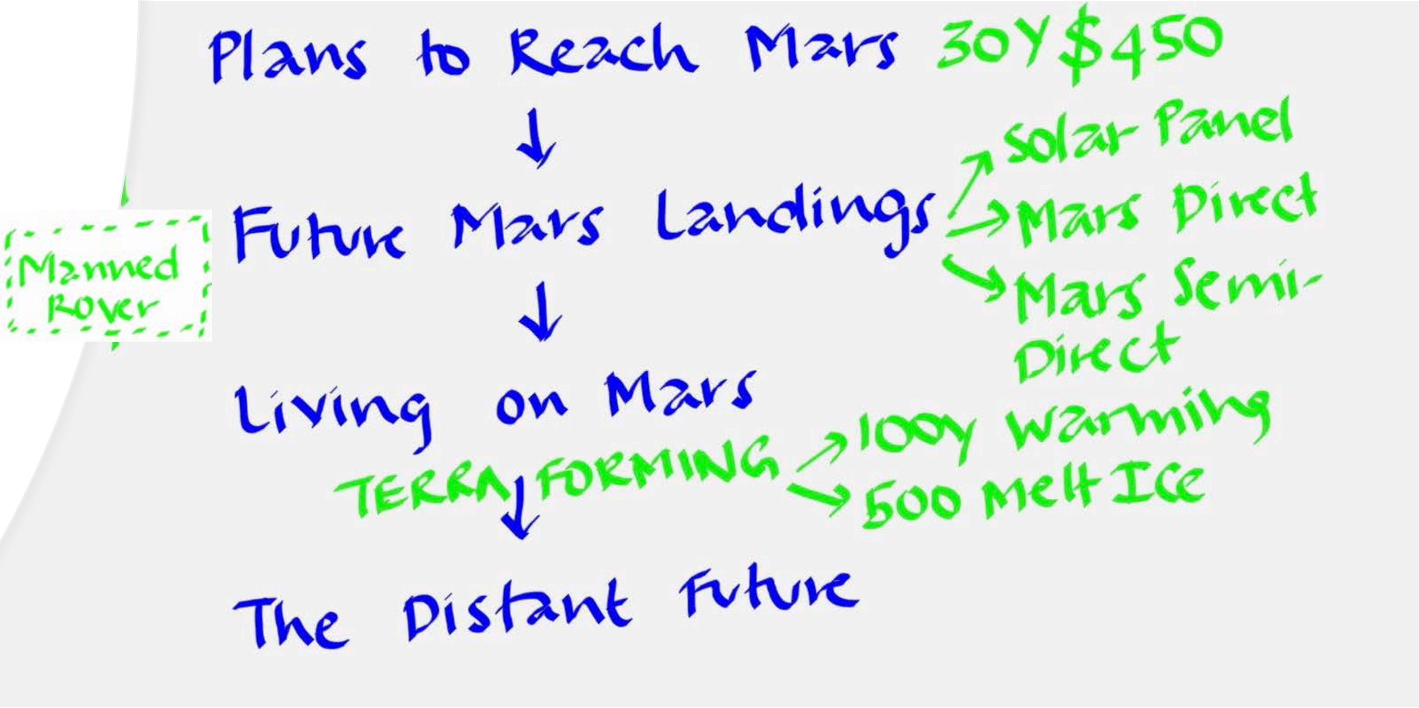
Dreams of Space Travel 20th century
↓
First Space Travellers 1957-1961
↓
Start of Space Race 1961
↓
Preparing for Apollo 1960s
↓
Apollo 1 & Apollo 8 1960s
↓
The Saturn V Rocket 1960s
↓
Apollo 11 Lifts Off 16th July 1969
↓
Command Module ← Columbia and Eagle → Lunar Module
Command Module ↓ Michael Collins
Lunar Module ↙ Neil Armstrong ↘ Buzz Aldrin
↓
'One Giant Leap'
↓
Return to Earth — Lunar Roving Vehicle
↓
Russia ← The Final Moon Missions → NASA
Russia ↓ unmanned Probes
NASA ↑ Lunar Roving Vehicle; NASA ↓ +6 Apollo Missions (1972)
↓
Skylab & Salyut
1973 ↓ 1974-1986 → Mir (1986-2001)

Unmanned Space Probes - Jupiter, Saturn, Uranus, Neptune align — Voyagers in the Solar System 1977-2010
↓
Reusable Spacecraft 1950s & 1960s
↓
Prepare for Lift-Off! ↗ External Fuel Tank ↘ Solid Rocket Boosters
↓
Living in Space
↓
-△ (ET & SRB) From Launch to Re-entry 1980s
↓
Eye on the Universe 1990 - Hubble Space Telescope
↓
Reusable Craft : Different Types 2001
Space Tourism to orbit 2° single stage
↓
Probes to the Red Planet 1965, 1975, 1997...
↓
Discovering More — 1st Manned Mission 2020
↓
Lord of the Rings 1997, 2004, 2005
↓
2010 End of Space Shuttle Programme — Present and Future Missions — 2020 Moon Landing
↓
The International Space Station 1998 ↗ 1984 President Regan ↘ 1993 President Clinton
↓
30-40m Surviving in Space (6-8m → 18-24m → 6-8m)
↓

<u>Planned timetable for Mars Direct Flight:</u>

- Year 1 – Robotic Fuel Plant Lands
- Year 3 – First Crew arrives
- Year 5 – Crew returns to Earth(Spacecraft powered by fuel made by fuel plant in year 1)
- Year 5 or 6 – 2nd Fuel Plant arrives → Support next manned mission

What's the catch? The threats of LDST – Microgravity, Radiation, the unknown.



Why did we lose momentum?

Won the Space Race – at the cost of $22 Billion Moon Landing

Fading interest in Space Exploration ever since(→SpaceX sparking it)

Difficulty in justifying public expenditure → Political pressures → Loss of grants(→ Reusable Spacecrafts Inventions i.e. -**Δ**)

Shift in focus: Unmanned > Manned Mission

Man-made dangers – Space Litter(Catastrophic! 2^0 Collision)

What’s stopping us from proceeding with a manned mission to Mars? And beyond?

Threats of Long Duration Space Travel – Microgravity, Radiation and the unknown yet to be established

Funding – $450 Billion(if everything worked according to plan)

Time – 30+ years

Findings from existing Literature

Protective spacesuit equipment known as **Penguin Suit** is used to reduce the threats arising outside the magnetosphere which exposes the human body to radiation.

Ground-Based Models to quantify Post-High Linear energy transfer exposure to extra vehicular activity using **blood samples**.

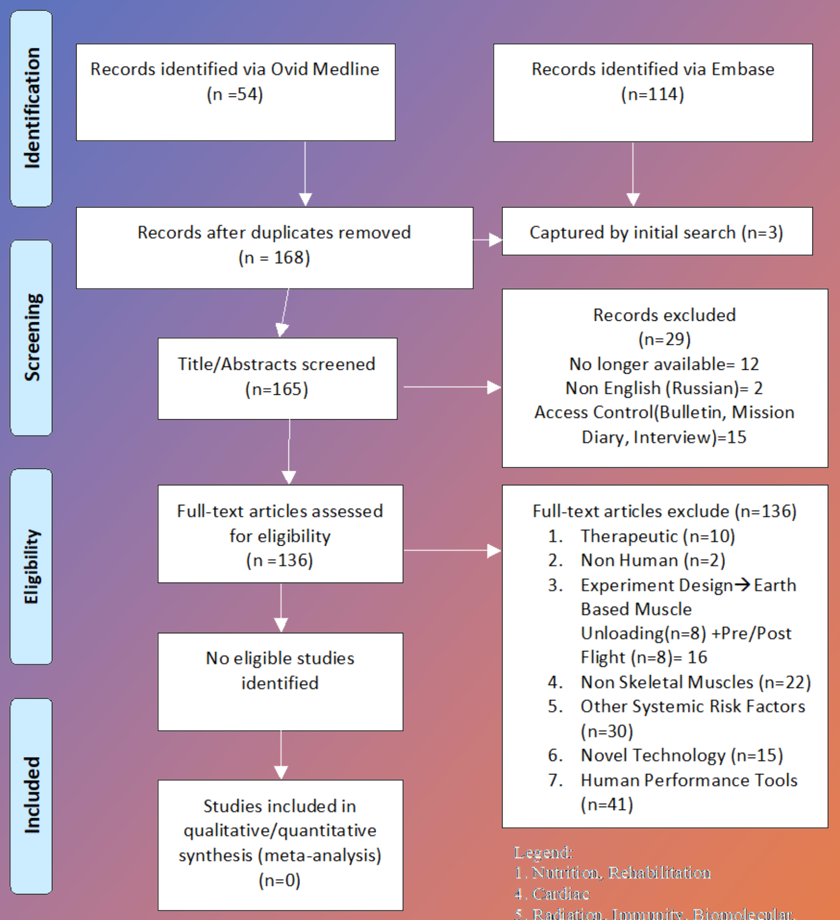
Advance Simulated Training at **Buoyancy Labs** is not sufficiently preparing astronauts to adapt on exposure to the harsh environment of the space missions. This causes irreversible damage to the Musculoskeletal System.

Findings from **"Advances in Space Technology"** by the NSBRI team highlights **1-1.6% bone loss per month** compared to **0.8-1.6% per year in Post-Menopausal Women** and **6-10% Muscle Wasting within Short Duration Missions to >10% Long Duration Space Travel**. They are the pioneers in devising new technologies such as <u>Neutron Spectrometer</u> and the <u>time of flight Hydrogen Mass Spectrometer</u> to assess flight radiation and critical biomarkers identified before through Ground-Based analysis of urine samples of astronauts Post-Flight.

Methods

- **Scopus**
- **Proquest**
- **Digital Encyclopedia of Applied Physics**
- **NASA Research Roadmap**

PRISMA 2009 Flow Diagram



Legend:
1. Nutrition, Rehabilitation
4. Cardiac
5. Radiation, Immunity, Biomolecular, Sleep, Microflora and Physiology-Foetal, Renal, Sensorineural, Occular

Additional searches conducted utilising single terms with the intent of improving the sensitivity of our search in Scopus, Proquest yielded the same outcome

From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). *Preferred Reporting Items for Systematic Reviews and Meta-Analyses*: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

For more information, visit www.prisma-statement.org.

i.e What are we tackling? What do we know thus far?

Penguin Suit(Targeting - Radiation)

Ground-Based Models(Targeting - Extra Vehicular Activity)

Buoyancy Labs(Targeting - Musculoskeletal System)

1. 1-1.6% bone loss/month vs **0.8-1.6%/year in Post-Menopausal Women**

2. 6-10% Muscle Wasting - Short Duration Missions vs **>10% - Long Duration Space Travel**(How? Ground-Based analysis of urine samples of astronauts <u>Post-Flight</u>)

What are we tackling?

Microgravity

Radiation

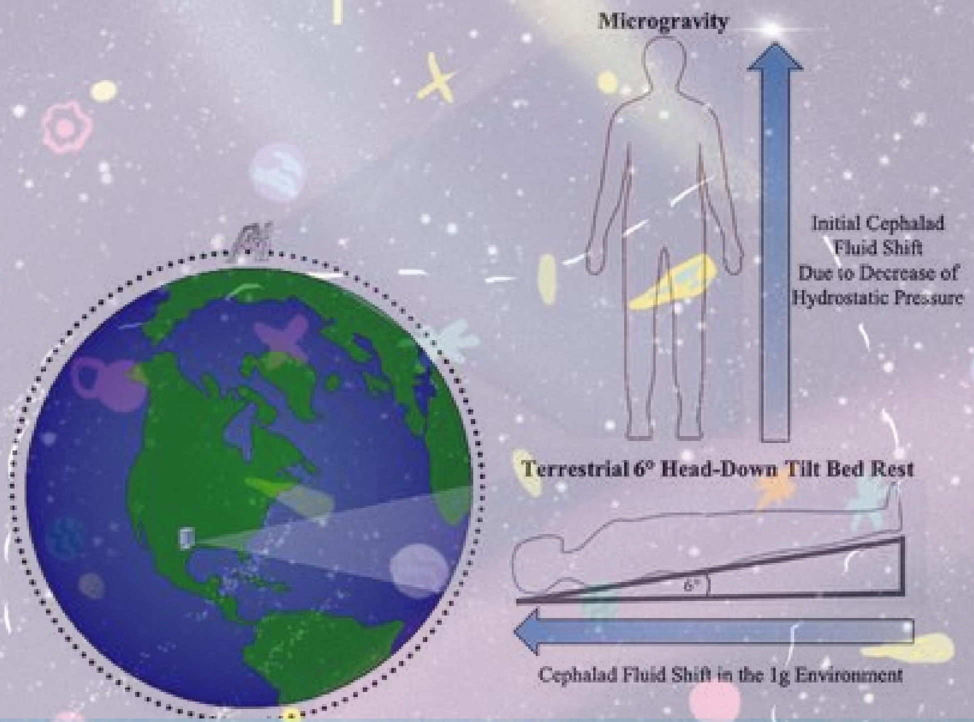
*Determine and Quantify the unknown → Formulate Therapeutic Countermeasures

How have we been tackling the aforementioned threats?

- Recurring Theme: Trial and Error
- Ground Based Models
  - Pre/Post Flight Data
  - Training at Buoyancy Labs
  - Hibernation Studies

Flaws:

1. Hard to mimic microgravity
2. Contrast pressure variation



How do we have to tackle the aforementioned threats moving forward?

Step 1: Gather data from existing pool of trained astronauts.

WHY?

a

DO WE NOT HAVE DATA?

YES. YES. We do!

1. Pre-Flight
2. Post-Flight

Insufficient → Formulate (efficient) Therapeutic Countermeasures

So…

Problem Statement + Solution = Clear

Picture this...

DATA

1. FIRST EVER
2. IN-FLIGHT
3. REAL TIME

But how?

What's the existing diagnostic imaging resources on the ISS?

ULTRASOUND ONLY

On-Orbit Hardware, ISS Medical Post

(Present Status)

Actiwatch Spectrum system	Cerebral cochlear fluid pressure analyzer(CCFP)	Distortion product otoacoustic emissions device(DPOAE)
Holter moniter	Human research facilitits 1 and 2(HRF 1&2)	On orbit laptops
Pulmonary function system(PFS)- Pulmonary function module(PFM), photoacoustic analyzer module(PAM), Gas delivery system(GDS),	Refrigerated centrifuge(RC)	Space linear acceleration mass measurement device(SLAMMED)
Human research facility ultrasound	Consumable Hardware-HRF supply kits(Purple and green), Blood collection, saliva collection, urine collection	Experiment specific hardware-fine motor skills, fluid shifts, lighting effects, microbiome

Let’s build upon that…

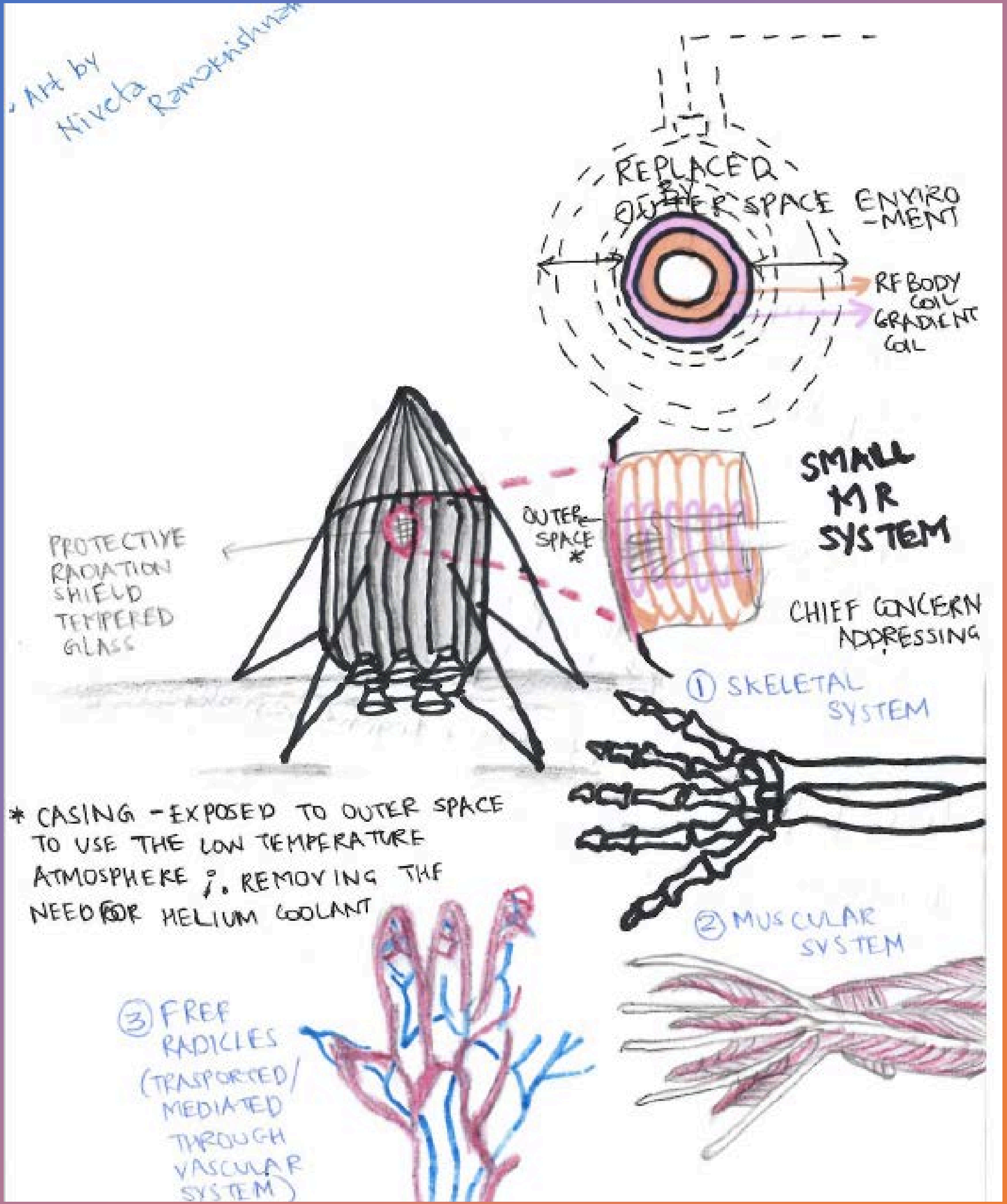
1. NON-INVASIVE

2. NON-IONISING

3. COMPACT

4. SPACE-READY(AUTOMATED, LOW POWER AND MASS)

Magnetic Resonance Imaging(MRI)

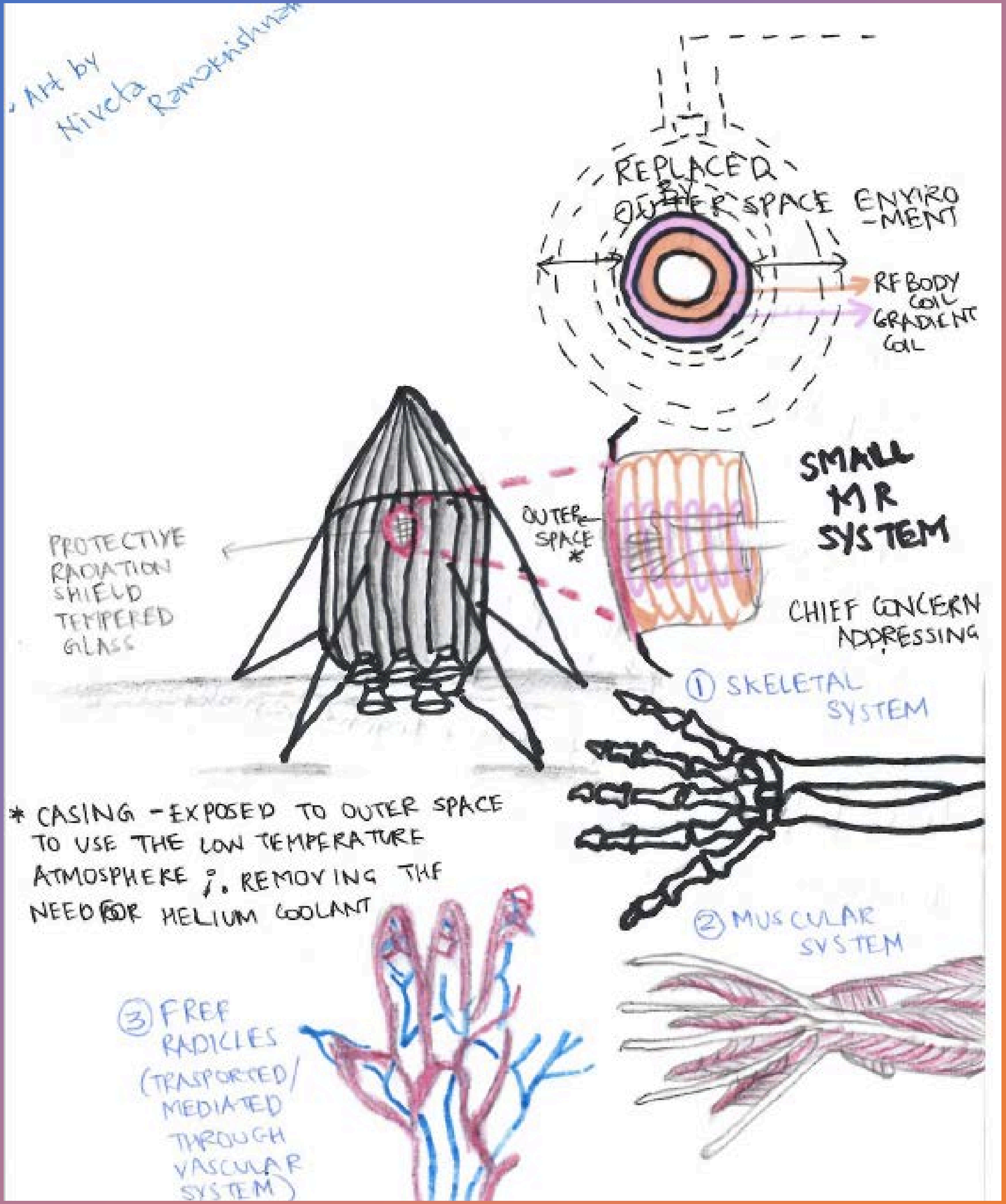


Proposal

- **A compact, space ready, high-field >5T MRI unit**
- Baseline of the rate of change of human physiology, in-flight, real time data

How?

ULTRA-COLD CONDITIONS OF OUTER SPACE SUPPORTS OUR PROPOSAL



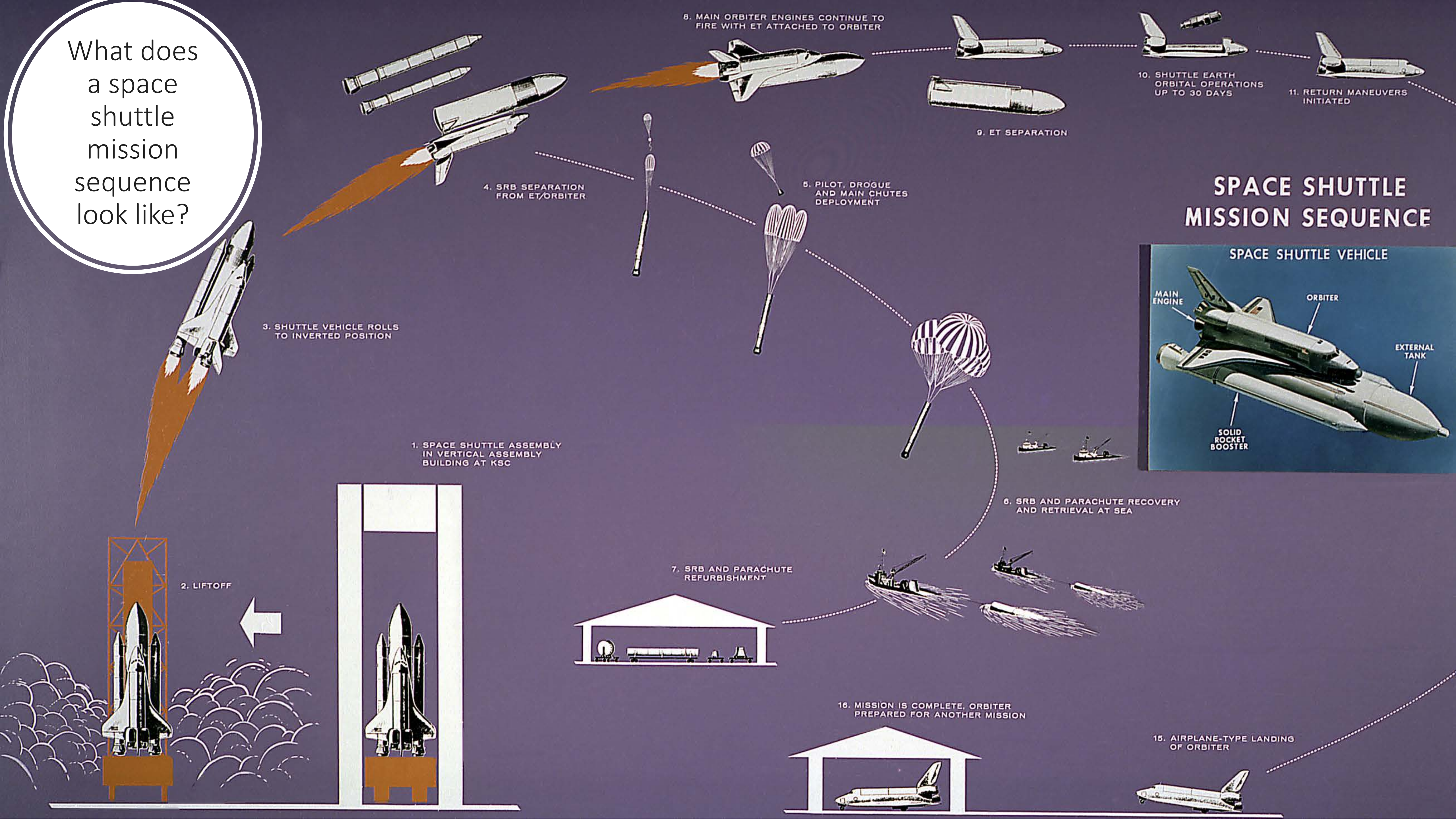
What makes it space-ready?

1. Superconducting Magnet positioned in Ultra-Low temperature of outer space
2. Suitably designed penetration chamber within the space capsule
3. Replacing the bulkiest cryogenic cooling system(Weight, Electricity Consumption, Cost and Expertise presence for an emergency Quench)
4. Data:

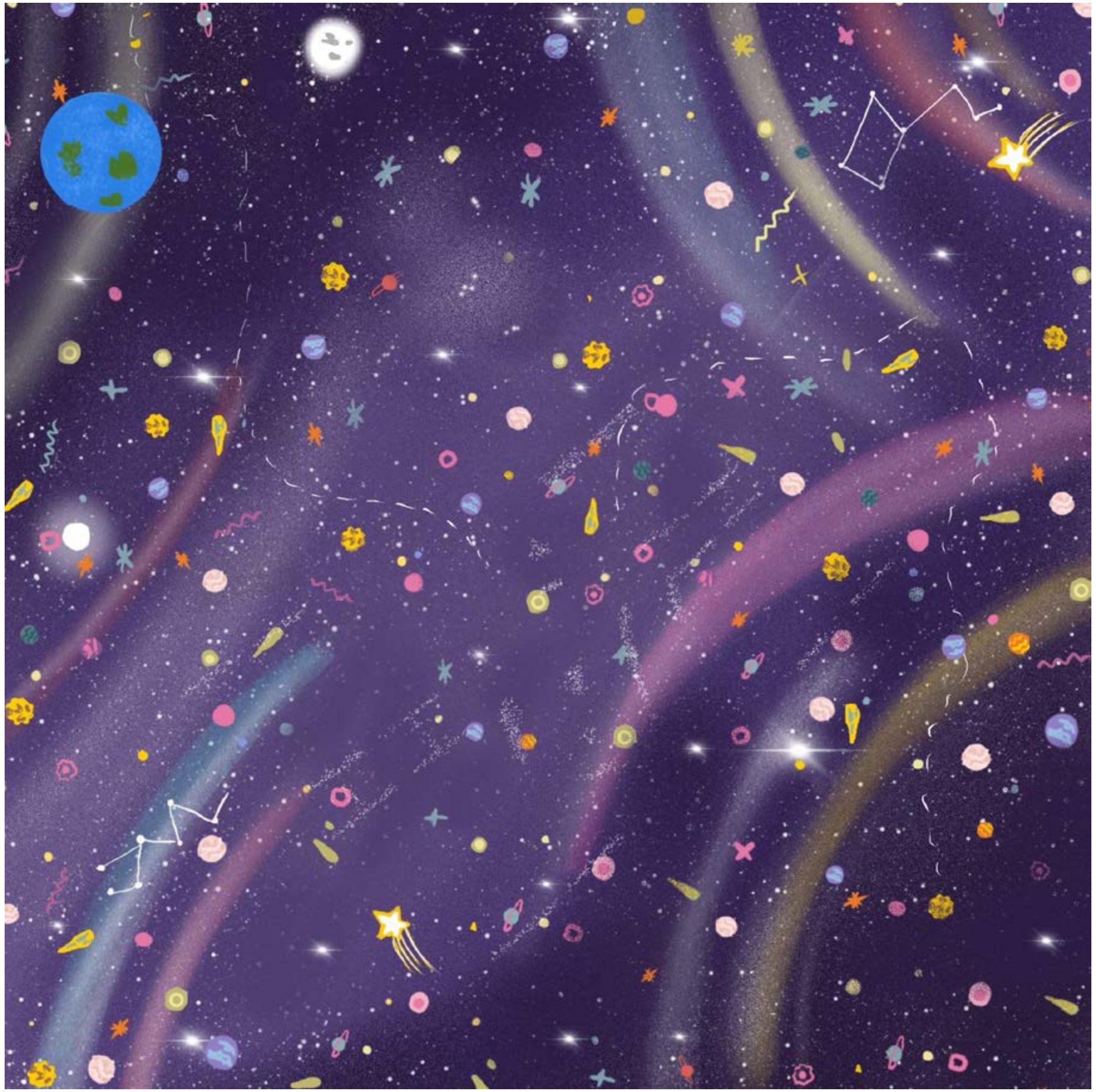
A. Transmitted to Earth via Satellite

B. Analysed and interpreted by ground based technicians at Columbia University

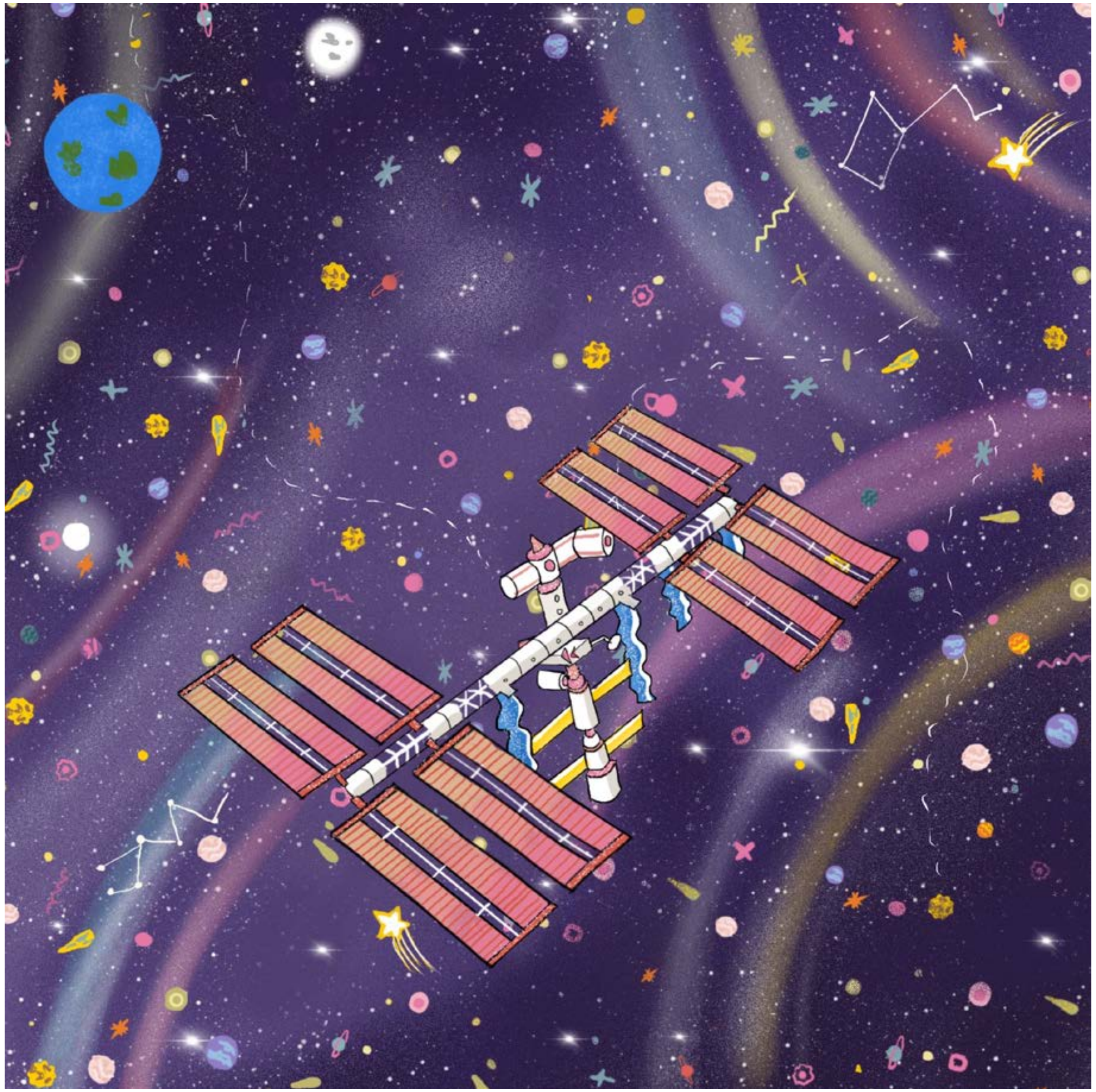
What does a space shuttle mission sequence look like?

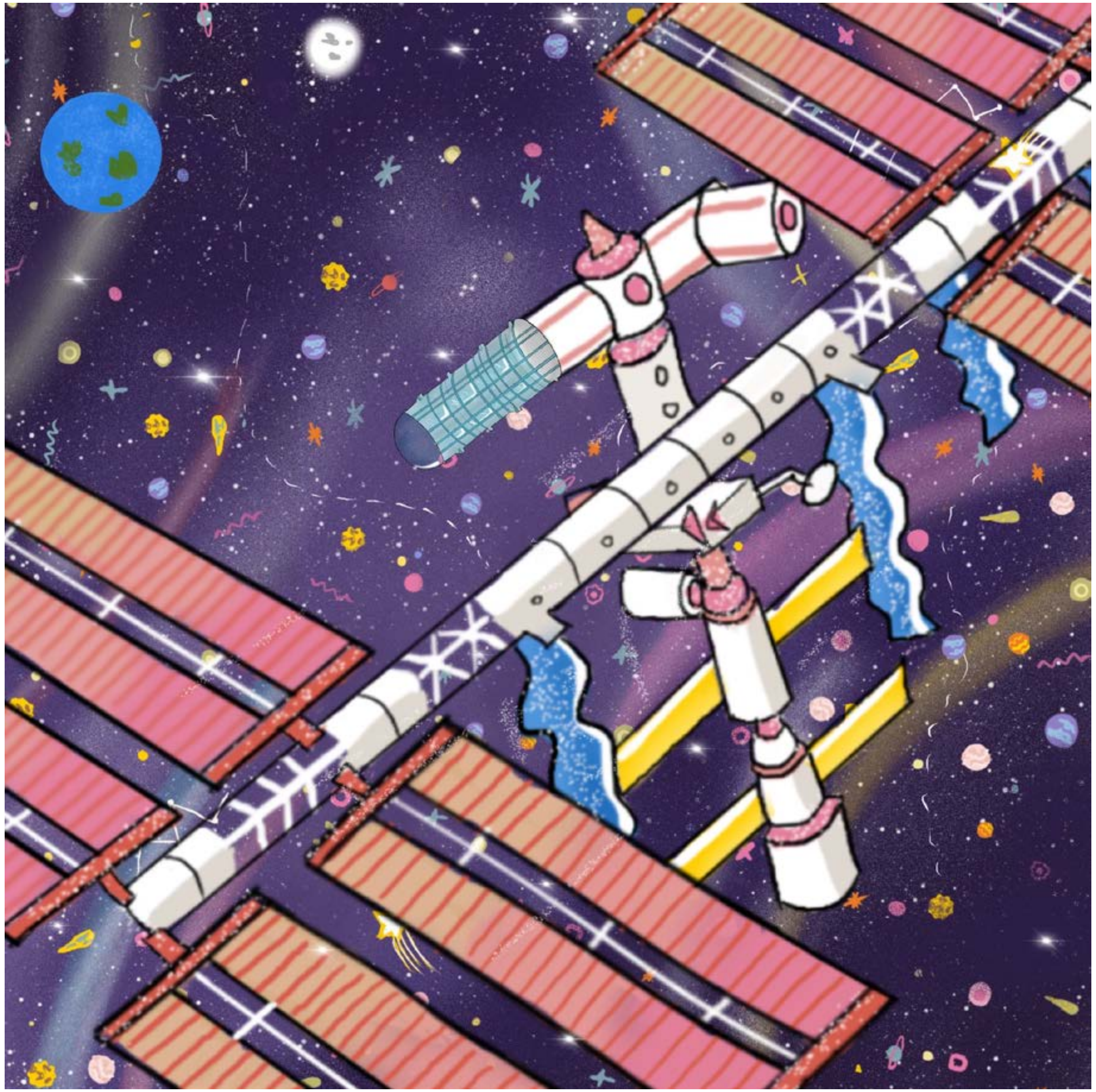


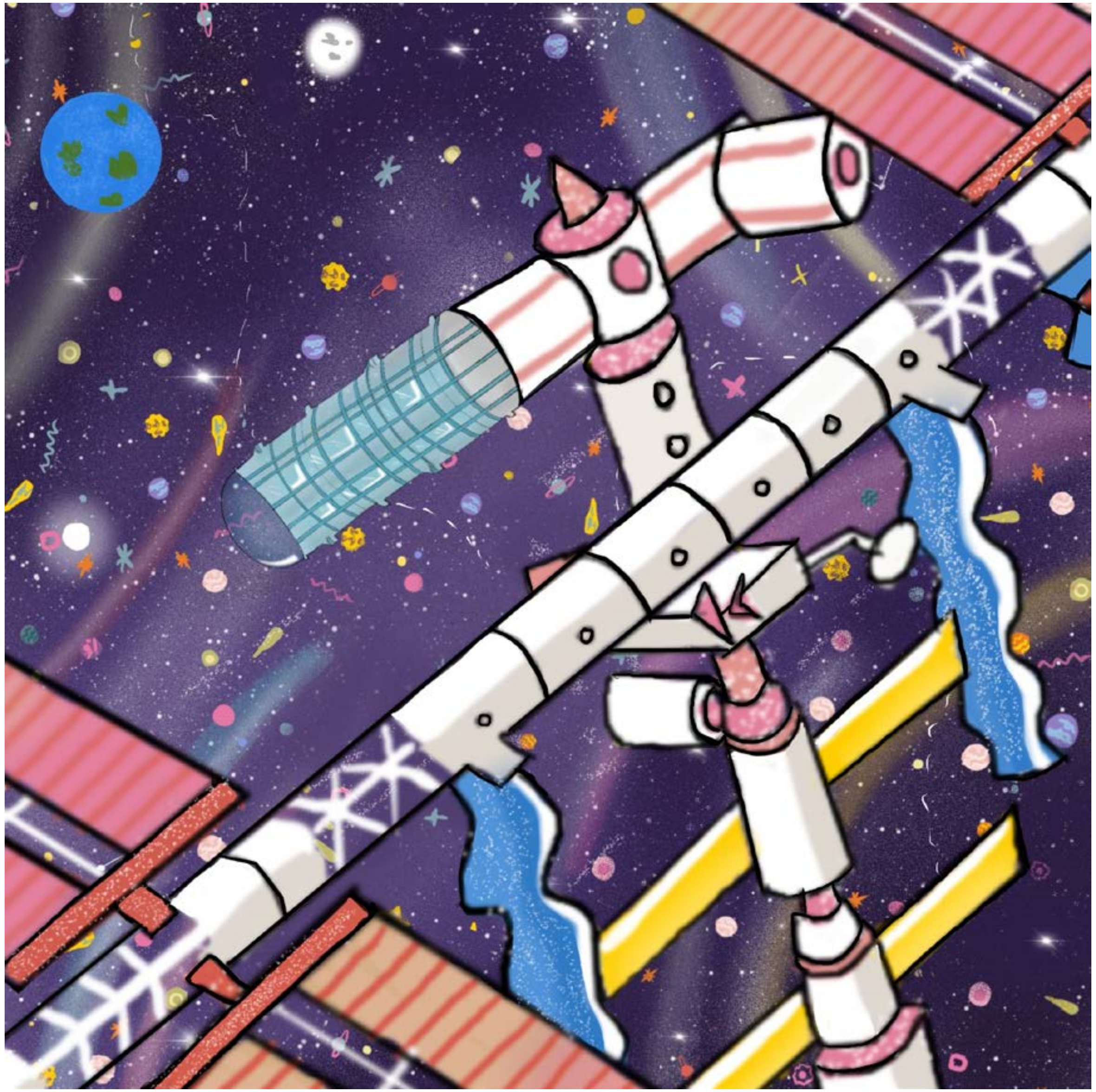
Here’s our take, on how a mission to the International Space Station will look like…with a space-ready MRI

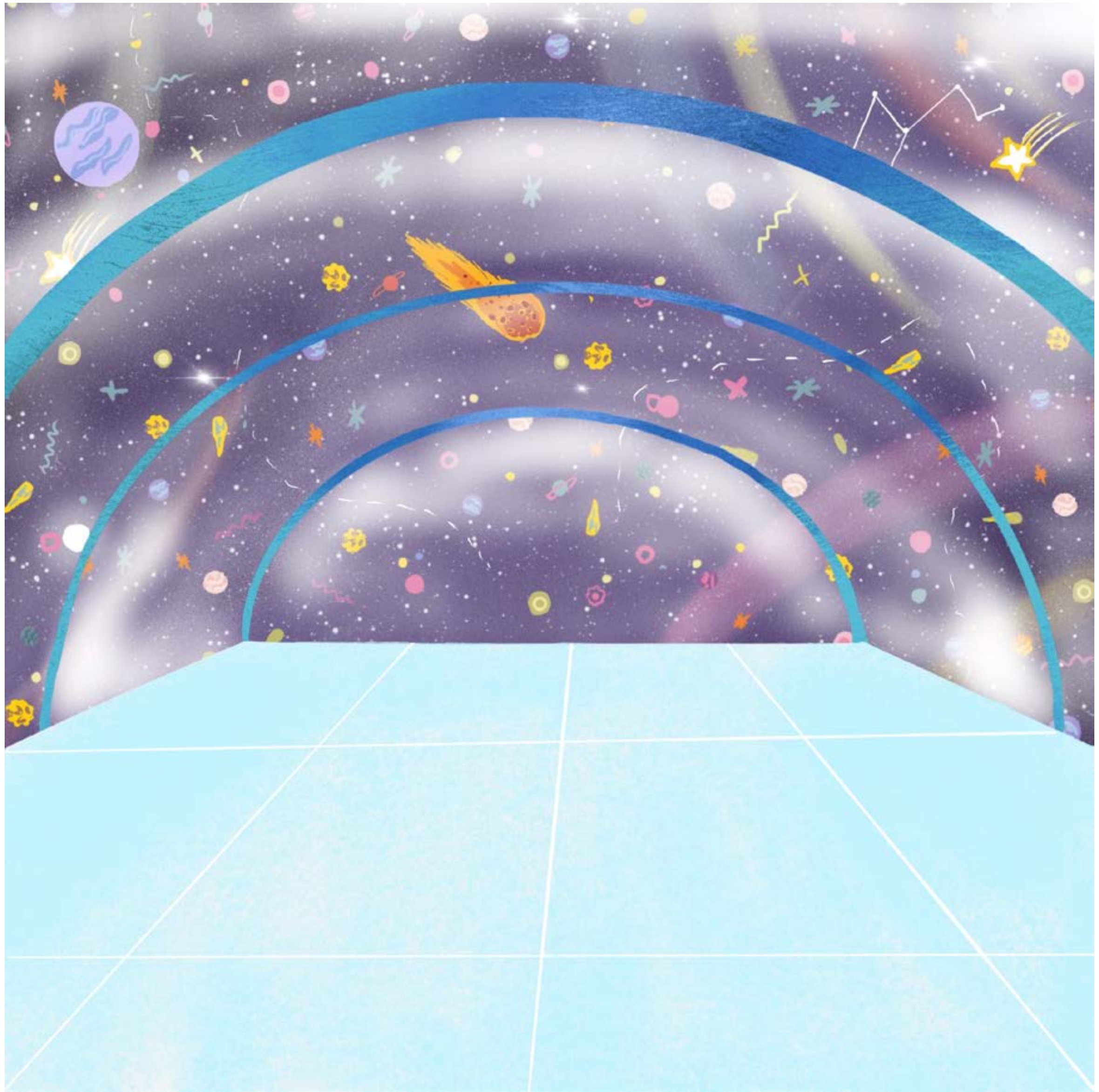


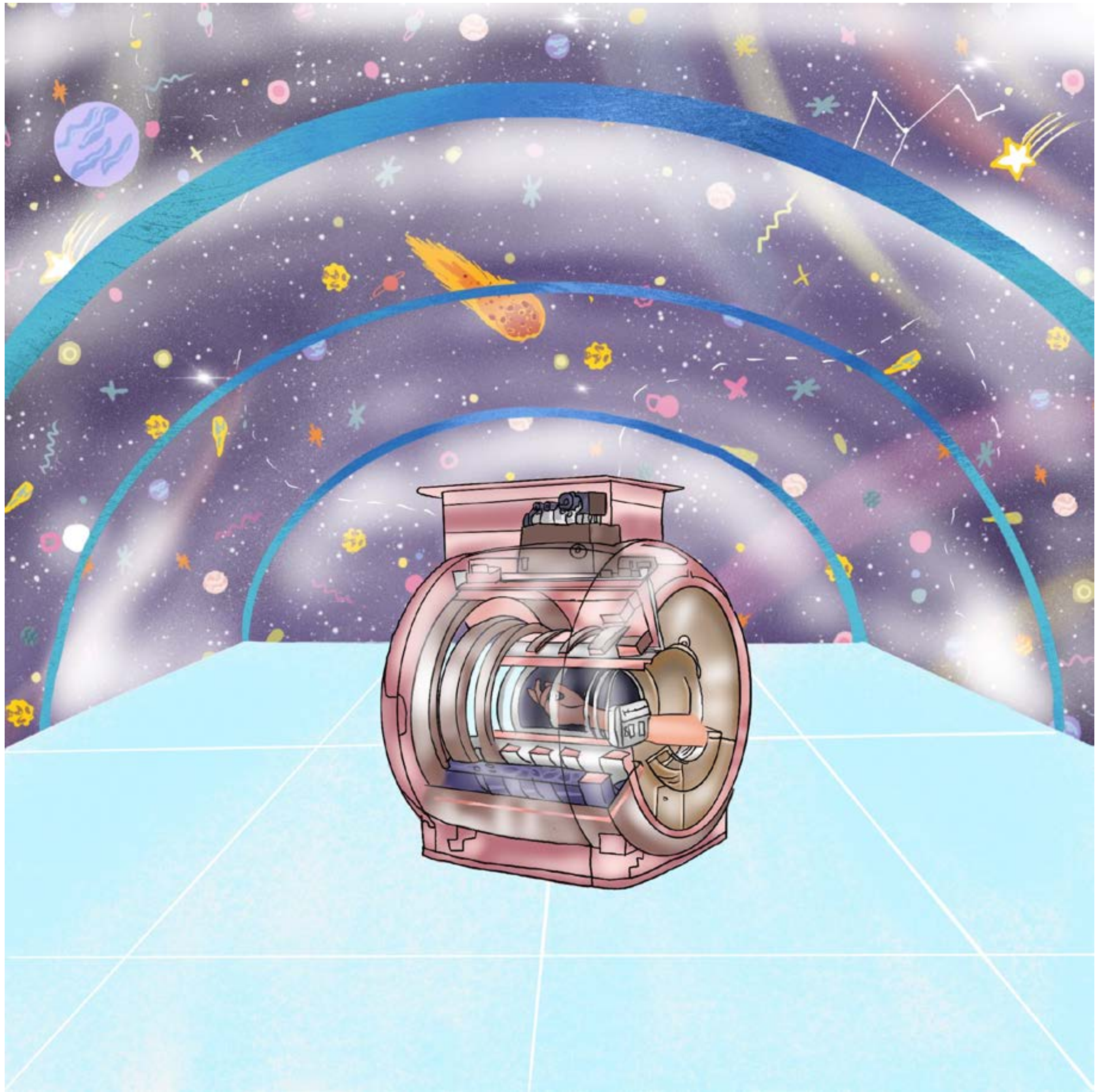

LAUNCHING IN
3…2…1

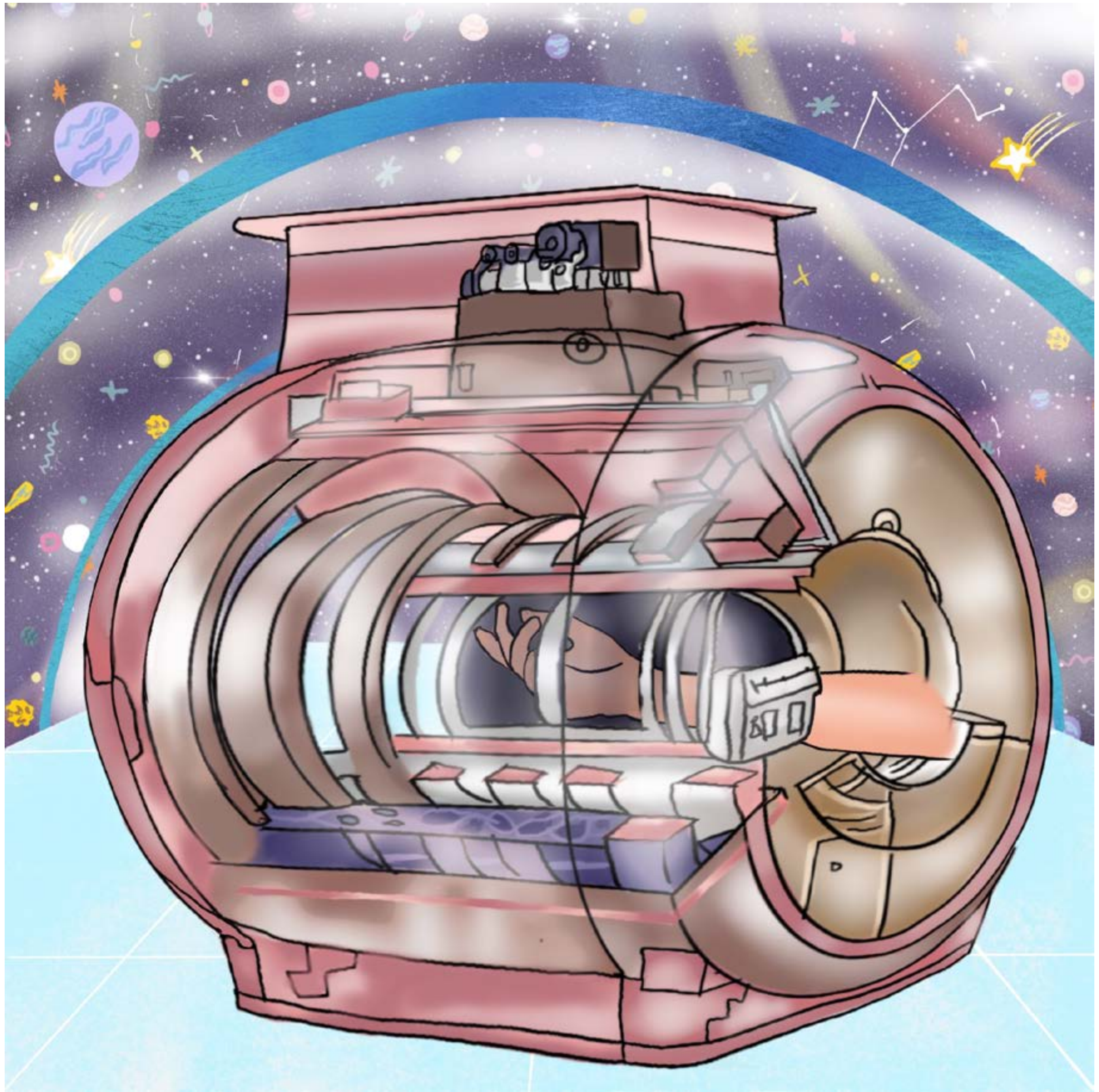


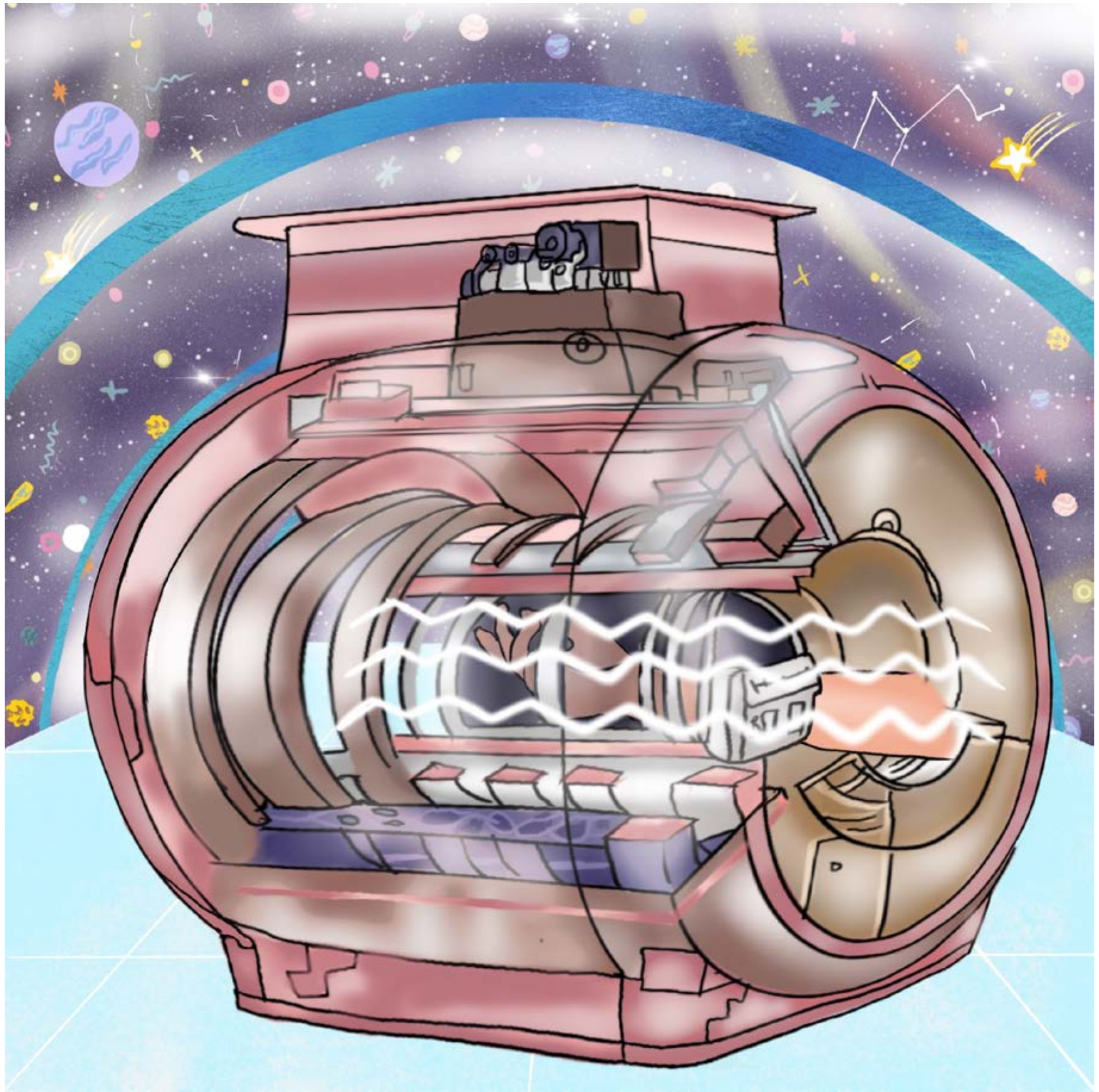


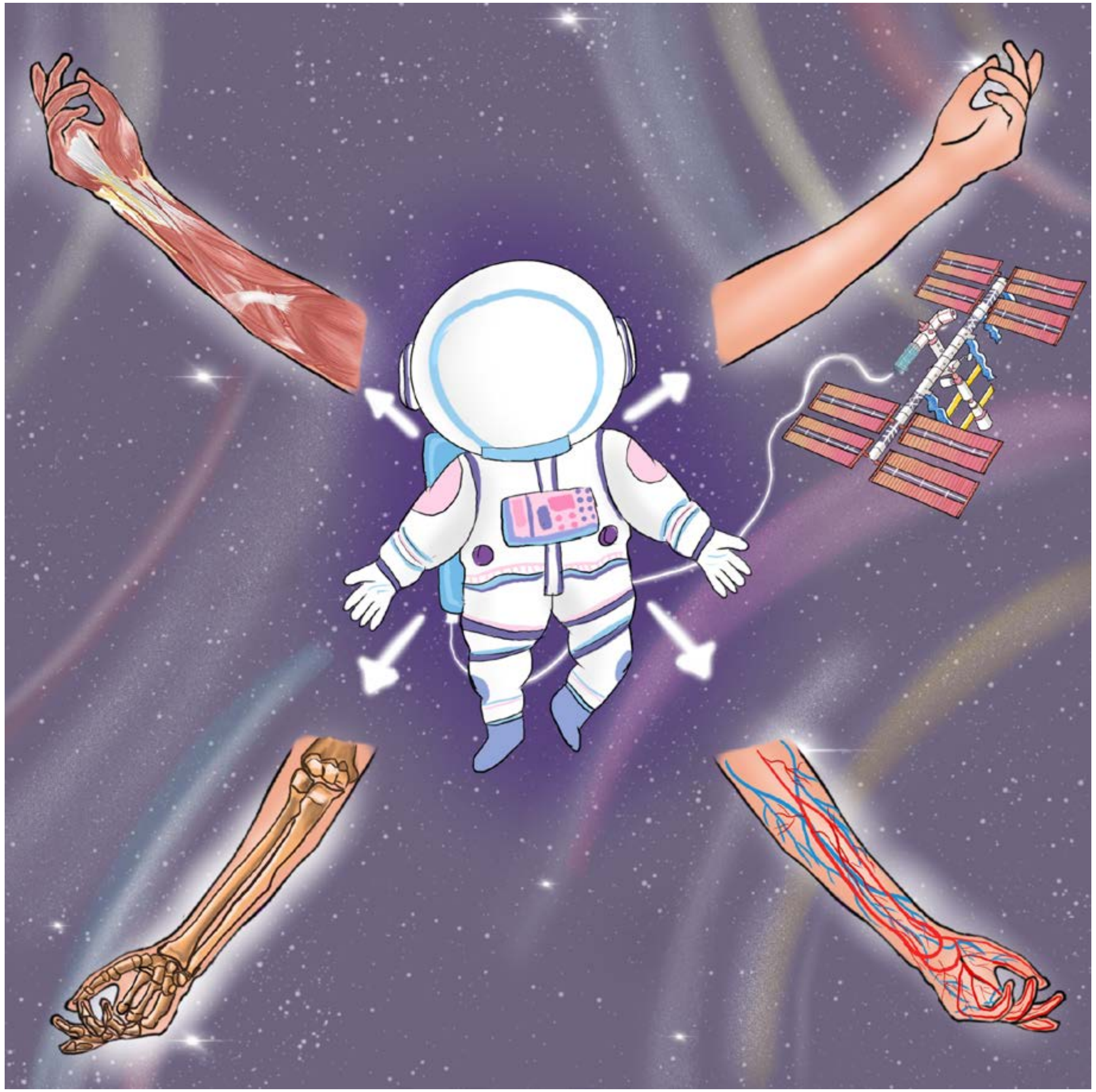













COLUMBIA
UNIVERSITY

Parameters	Ultrasound	Dual Energy X-Ray Absortiometry	MRI
Non-Invasive	Yes	Yes	Yes
Resolution	Low	High	High
Ionizing (Electromagnetic Spectrum)	No	Yes(10^{-8}-10^{-11})	No(10^{3}-10^{-1})

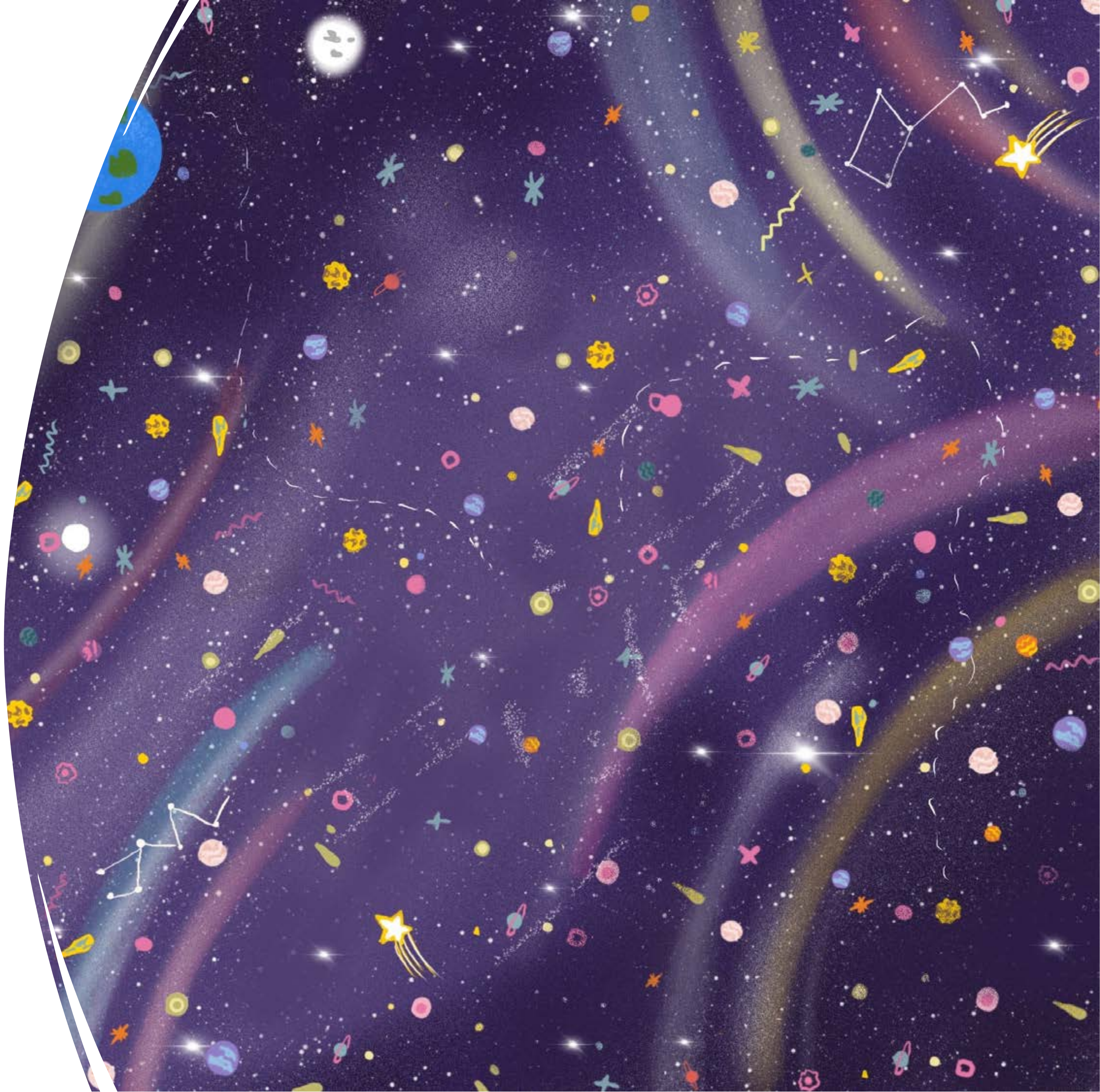
US vs MRI vs DXA

- The comparison of **existing in-flight ultrasound** to our **proposed small MR** system, where MR excels over ultrasound due to its **high resolution and minimised rate of error in acquiring quality images**.
- The preliminary findings of metric data observed among participants comparing Ultrasound to Dual energy x-ray absorptiometry(DXA) reported in the NASA Task Book Maps.
- Therefore, in spite of DXA and MR having excellent resolution, **MR** prevails over others due to added benefits of its **non-ionising, non-invasive** parameter. The rationale in choosing one imaging modality over another can be accounted for from simply noticing where they are in the extreme ends of the electromagnetic spectrum, the x-ray ionising wavelength at 10^{-8}–10^{-11} and MR radiofrequency waves non-ionising wavelength at 10^{3}-10^{-1}. The human body can be assessed at various levels of structural organisations such as at a molecular, cellular, organ and organ systems using MRI.

WHAT’S NEXT?

Conclusion

A feasible payload, biomedical engineered, compact MRI design will formulate therapeutic countermeasure in the form of nutrition, exercises and pharmacologically, as we lay the foundations of medical advancement for astronauts’ longer duration space travel.



Funding

Open to ideas!

What have I tried already?

NASA Nspires Grant

Columbia University Irving Medical Center

Department of Taoiseach

Efforts || Interest: Rural Medicine

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2019 Mortimer B Zuckerman Mind, Brain, Behavior Institute, New York

What's my background to Space Medicine?

- Build upon Dr Vaughan's working group findings at the Marshall Space Flight Centre
- Developed the interest to better understand the degeneration of the musculoskeletal system of the astronauts during their space exploration

2012 Johnson Space Centre, Houston

Space Studies(Mars Rover, Rocketry), Human Research Program, Training – Scuba Diving

Support Team and Advisors

1. **Ms Kathleen Durkin** - MR Research Administrator
Mortimer B Zuckerman Mind, Brain, Behavior Institute

2. **Mr John Usseglio MPH** - Informationist
Augustus C. Long Health Sciences Library

3. **Mr Tavis Allison** - Director of Grant Development
Columbia University Irving Medical Center

4. **Dr Wei Shen MD, MPH** - Assistant Professor of Nutritional Pediatrics,
Department of Pediatrics and Institute of Human Nutrition
College of Physicians & Surgeons, Columbia University
Director, Image Analysis Laboratory and Obesity Research Center.

5. **Dr Gopalan Raghavan PhD** - Quantum Information, Cryptography and Optical Properties Scientist
Department of Atomic Energy

6. **Dr Sridhar S Nambi MD** - Director of Endocrinology, Internal Medicine
St Barnabas Medical Center

7. **Mr James O’Grady** - Department of Taoiseach

THANK YOU!

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