Title: Observation of Telomere Length Changes in Deep Space Radiation Environment

Primary Point of Contact (POC) & email: Jose Leonardo Brenes Calderón (jose.leonardo.brenes@vanderbilt.edu).

Co-authors: David Limpus, Jennifer Dayanna Vargas Madrigal, Marlon Narváez, María Fernanda Guerrero Quesada.

Organization: Students from Vanderbilt University, Universidad de Costa Rica, Universidad Autonoma de Centroamerica, and Society of Women in Space Exploration Costa Rica.

(X) We apply for Student Prize.

( ) Please keep our idea confidential if we are not selected as finalist/semi-finalist.

Need:

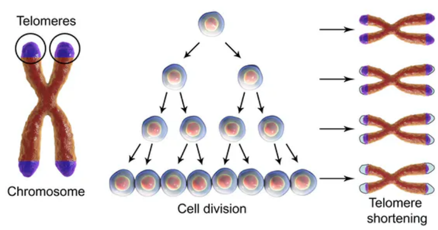
Between 2000 and 2015, according to the WHO, life expectancy at birth has increased 5.5 years, but healthy life expectancy at birth has only increased 4.6 years. In other words, people live more, but those additional years are not all quality years. A solution to this problem can be found in DNA: *telomeres*.

What are Telomeres?

Telomeres are the tips of chromosomes that protect DNA and preserve the stability of the genome, preventing DNA from being damaged or ruptured., allowing the DNA replication to take place successfully. However, for each DNA replication, the telomere lengths are shortened, causing aging, diseases such as cancer, neurodegenerative diseases and compromising the immune system.

How is telomere shortening related to aging and disease?

Telomeres function as a clock for cells. Thanks to the repetitive sequences it prevents the ends of the chromosomes from being broken or damaged in cell division, however telomeres also divide, losing their length at each division. The shortening of telomeres is a symbol of aging in humans, and leads to disease. Telomeres prevent the development of diseases related to chromosome stability, such as cancer, neurodegenerative diseases and diseases of the immune system.



Spirit of Inquiry: Rosalind Franklin.

The objective of the mission is to study the behavior of telomeres in deep space.

NASA has conducted telomere length studies in low-Earth orbit with twins Scott and Mark Kelly and observed that telomeres lengthen. The duration of that experiment was comparable to that of the Mars transit, but the effects of cosmic radiation and its interactions with the shielding the astronauts will be exposed to on their way to Mars have not yet been tested. Spirit of Inquiry will observe changes in telomere length in response to the extreme deep space environment, using yeast as a model. This will provide a better understanding of the aging process, cellular reproduction mechanisms and genetic mutations (which lead to cancer and many other deadly or incurable diseases) in order to help people on Earth and astronauts on their way to Mars.

Yeast to study the human genome:

For the experiment, yeast will be used to study the behavior of telomeres in deep space. Specifically, S. Castelli because it is known for having regular telomere sequences (TCTGGG$(TG)_{1\text{-}4}$).

<u>Sustainable Development-goals:</u>

1. **Health and well-being:** Studying how telomeres behave in the deep space environment will improve our understanding of the mechanisms that affect aging and disease, thereby improving quality of life and increasing life expectancy.

2. **Innovation:** This mission will serve as a demonstrator of using proven technologies to quickly develop and run new experiments while accelerating transfer of existing technologies to emerging space organizations. This is important for increasing democratization of deep space.
3. **Reduced inequalities:** The knowledge gained can help develop affordable treatments to attenuate the effects of cancer, cellular aging and prevention of neurodegenerative and autoimmune diseases, reducing inequalities derived from elderly care and lack of access to treatments .

Mission Objectives:

- **General Objective:**

Investigate the effects of deep space radiation and microgravity on telomeres using yeast as a model organism.

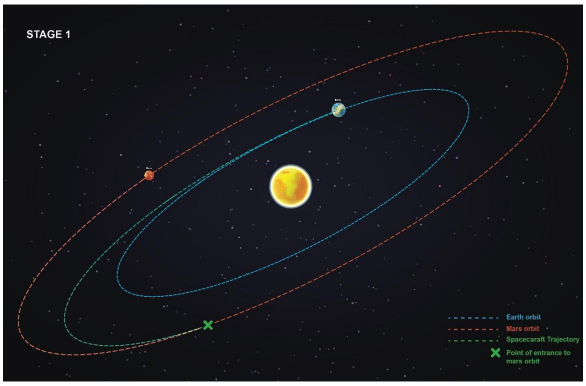
- **Specific Objectives:**

1. Contribute to future human missions to Mars by deepening the understanding of radiation effects on telomere health. This reduces risk to astronaut health during deep space flight.
2. Compare samples exposed to cosmic radiation with radiation shielded samples to evaluate the effectiveness of novel shielding technologies and their potential secondary effects.
3. Contribute to regenerative medicine by observing telomere length changes in deep space to better understand the aging process and cell rejuvenation, and identify mechanisms of cancer growth.

Concept of Operations including orbital design

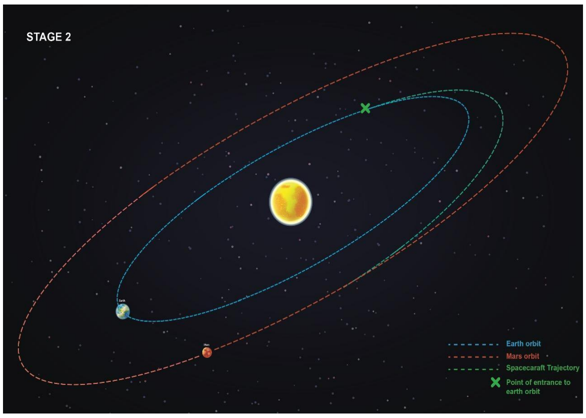
1. **First phase:** sample preparation and launch (6 months before launch).

The satellite is delivered to the launch provider 6 months in advance. The yeast remains dehydrated during this time. Approximately 6 days after launch the two 16U cubesats are released and perform a detumble maneuver before initiating a line abreast flight formation on an orbit similar to a Mars transfer orbit. The orbit's trajectory leaves Earth and intersects the orbit of Mars, simulating a Mars transfer orbit without the limitation of waiting for transfer windows.



2. **Second phase:** experiment operations (6 days after launch -8 months after).

The yeast is rehydrated. The lengths of the telomeres on the satelites Rosalind and Franklin, and Earth control are promptly recorded. This phase lasts for approximately 8 months, during which the yeast samples in Rosalind and Franklin are exposed to cosmic and solar radiation and observed once a day.



3. **Third phase:** post mission possibilities (8 months after launch - 14 months after launch).

After the main experiment is conducted there are different options to utilize the hardware further. The mission could be extended 6 months or the cold gas thrusters could be used for autonomous maneuvering tests. Both of these options are limited by the amount of stored propellant and hardware degradation .

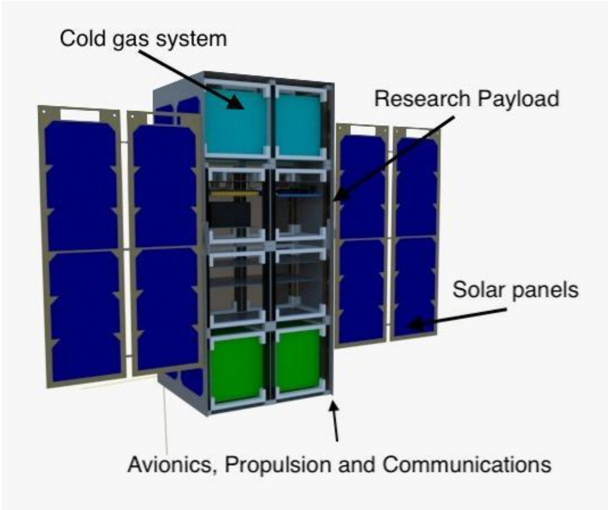
Key Performance Parameters

1. Telomere observation will be performed once daily over a period of 8 months.
2. The yeast will be supplied with nutrients and rehydrated after Spirit of Inquiry exits Earth's magnetosphere.

3. Each satellite will carry 10 microfluidic cartridges. Each cartridge will contain eight unhealthy short telomere yeast samples, and eight healthy normal telomere yeast samples.
4. An ambient temperature within the research payload of 23 C ± 1.
5. The downlink bit rate ranges from 8 bit/s to 32 kbit/s. Uplink has three modes: 16 bit/s, 125 bit/s, and 1000 bit/s. The TT&C and communications system is effective up to 2.5 AU. The maneuverable antenna is accurate to 1°. QPSK modulation will be used.

Space Segment Description

The mission will consist of two proven 16U cubesat buses weighing approximately 22 kg each. Each bus will contain all of the systems necessary to run the experiment and maintain the spacecraft in a stable condition. Rosalind will contain shielding against cosmic radiation as part of its research payload, and Franklin will have minimal shielding. The cascading effect of cosmic radiation particles colliding with shielding materials can be even more dangerous than the cosmic radiation itself. Thus, to avoid ricochet of particle cascade from shielding material, the shielded and unshielded samples will be located on separate satellites. To reduce RF power consumption, the satellites will be able to share information between them via L-band antenna, which will also serve as a redundancy in case of hardware failure.



3D model of 16U cubesat

Experiment Equipment:

For the experiment, yeast will be used to study the behavior of DNA in deep space, specifically S. Castelli, because it is known for having regular telomere sequences (TCTGGG(TG)$_{1\text{-}4}$). This is crucial for simulating human telomeres. Inserting Green Fluorescent Proteins (GFPs) next to these sequences will allow the length of telomeres to be monitored. The proteins fluoresce when exposed to light of a specific wavelength, which is provided by an LED. Photodiodes detect the fluorescent light and record the intensity. Intensity corresponds to the length of the telomeres. The Rosalind and Franklin intensities are compared to a control on Earth.
To reduce development time and risk, the yeast will be stored and grown with the system developed for NASA's Biosentinel mission. Microfluidic cartridges will contain the yeast. One cartridge will have 16 wells. Eight wells will be filled with unhealthy yeast that have short telomeres, and the other eight are filled with healthy yeast with normal telomeres. The cartridges will allow for nutrient control and a stable growth environment. Heating elements will also be used for temperature stability. The yeast will be deprived of sugar and water until the spacecraft is in the presence of deep space radiation. On earth, 10 microfluidic cartridges will be grown in the same system, and monitored as the control. The yeast aboard Rosalin and Franklin and control yeast will be recorded at the same time and same frequency (12:00 PM EST, once every 24 hours).

Communication Equipment:

Spirit of Inquiry will be using a similar TT&C and communications system used by PROCYON. Spirit of Inquiry will be equipped with two low gain X-band patch antennas for uplink, two low gain X-band patch antennas for downlink, one medium gain L-band patch antenna, one medium gain X-band patch antenna, and one maneuverable high gain X-band antenna. The X-band frequency will be utilized for uplink/downlink communication, and the L-band will be used for satellite to satellite communication. The maximum RF power output of the system is 17 watts using high-efficiency

(30%) Gallium-Nitride power amplifiers. For ground operations, we will use NASA's Deep Space Network. In lieu of a GPS, Spirit of Inquiry will use pseudo-noise ranging and Delta-Differential One-Way Range (DDOR) for orbit determination, and two-way Doppler velocity measurement.

Position and Attitude control:
For attitude and position control, Rosalind and Franklin will use an IMU, a star tracker, and sun sensors. For attitude adjustments, the spacecraft will use reaction wheels, which provide the precision necessary to point the patch antennas. The satellites will be also equipped with cold gas thrusters for detumbling after deployment and desaturating the reaction wheels. Cold gas thrusters have already been used in CubeSats and after the mission, they could also be used for autonomous proximity operations tests. The cold gas thrusters will have a delta-v budget of approximately 8.5 m/s consisting of 0.1 m/s for detumbling, 3 m/s for desaturating the reaction wheels for a year, and 4.1 m/s for a possible mission extension or potential autonomous proximity operations tests. The satellites will also have monopropellant thrusters to adjust its trajectory for collision avoidance maneuvers. This system will have a delta-v budget of 30 m/s for object avoidance maneuvers but will have up to 87 m/s of delta-v available.

Power Generation and Storage:
Spirit of Inquiry will be equipped with high-efficiency (30%) Gallium-Arsenide solar panels. They will produce approximately 147 W at 1 AU and 62W at its furthest point from the sun 1.55AU. For power storage, 161 Wh Lithium-Ion batteries will be used. The idle electrical load of each satellite will be approximately 46 W. Peak power demand will reach up to 111 W for 1 hour (once every 24 hours). During peak power demand, the battery unit delivers 48 W. Assuming a battery degradation of 33%, the battery could support peak power demand for 2.4 hours. At the mission's furthest point from the sun (1.55 AU), the battery unit could be fully recharged in 10.5 hours.

Technologies that must be further developed:
Inserting fluorescent proteins (GFPs) next to telomere sequences.
Cosmic radiation shielding.
Cold gas attitude thrusters.
Extended mission: autonomous multi-vehicle deep space maneuvering and stationkeeping.
Implementation plan:

Estimated prices for the mission in USD				
Research $58,000	**Electronic Power: $98,400**	**Propulsion $19,800**	**Communications $20,000**	**Structural $24,300 each**
S. Castelli yeast Fluorescent Protein Photodiode sensor Temperature sensor Radiation sensor Pressure sensor LEDs	Solar Panels Batteries	Reaction wheels IMU Cold Gas Thrusters Monopropellant thruster Star Tracker Sun sensors	Low Gain Patch Antennas PSK modulation Two medium gain patch antenna X band patch antenna	16U cubesats

Risks	
R&D for Telomere Observation Method	Medium
Battery Degradation	Low
Cosmic Radiation Shielding development	Medium
Radiation Damage to instruments	Medium
Yeast life support failure	Low
Insufficient funding	High

Risk mitigation

Most of our risk mitigation comes from having redundant systems between the two satellites, not depending on a firm launch window and utilizing proven technologies. This will reduce the impact of hardware failure or delays in development. The power supply is of utmost importance. In case the power supply fails, an emergency power reserve will be placed, which can supply 5 Amps. for 20 hours. Also in the event that the temperature exceeds the acceptable range for a sample, an alarm will be displayed that activates a low power cooler that controls the temperature while the fault is investigated.

Table for Project Implementation 2022-2024	
Phase	**Duration**
Design	5-6 months
Development(experiment & software)	8 months
Construction	4 months
Testing	2 months
Launch Vehicle Integration	6 months
Primary Mission	8 months

References

La esperanza de vida ha aumentado en 5 años desde el año 2000, pero persisten las desigualdades sanitarias. (2016, 19 mayo). Recuperado 2 de julio de 2021, de https://www.who.int/es/news/item/19-05-2016-life-expectancy-increased-by-5-years-since-2000-but-health-inequalities-persist

Healthy life expectancy(HALE) at birth (years). (2000–2015). Database. World Health Organization. https://www.who.int/data/gho/data/themes/topics/indicator-groups/indicator-group-details/GHO/healthy-life-expectancy-(hale)

Mattern, K. A., Swiggers, S. J. J., Nigg, A. L., LöwenbergB., Houtsmuller, A. B., & Zijlmans, J. M. J. M. (2004). Dynamics of Protein Binding to Telomeres in Living Cells: Implications for Telomere Structure and Function. *Molecular and Cellular Biology*, *24*(12), 5587–5594. https://doi.org/10.1128/mcb.24.12.5587-5594.2004

Kaishima, M., Ishii, J., Matsuno, T., Fukuda, N., & Kondo, A. (2016). Expression of varied GFPs in Saccharomyces cerevisiae: codon optimization yields stronger than expected expression and fluorescence intensity. *Scientific Reports*, *6*(1). https://doi.org/10.1038/srep35932

The Smart Communication Systems of the Ultra-small Deep Space Probe. (n.d.). ISAS. Retrieved June 7, 2021, from https://www.isas.jaxa.jp/en/feature/forefront/150424.html

Li, J. (2000, 20 octubre). Green fluorescent protein in Saccharomyces cerevisiae: real-time studies of the GAL1 promoter. Recuperado 20 de julio de 2021, de https://pubmed.ncbi.nlm.nih.gov/10972930/

Products. (2018, July 16). CubeSatShop.com. https://www.cubesatshop.com/products/

Stevenson, T., & Lightsey, G. (2016). Design and Characterization of a 3 D-Printed Attitude Control Thruster for an Interplanetary 6 U CubeSat.

Li, J. (2000, 20 octubre). Green fluorescent protein in Saccharomyces cerevisiae: real-time studies of the GAL1 promoter. Recuperado 20 de julio de 2021, de https://pubmed.ncbi.nlm.nih.gov/10972930/