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Creating Human Experience through Food in Space

Carla Uyeda[a]*, Madhu Thangavelu[b]

[a] *Graduate Student, University of Southern California, Viterbi School of Engineering*, Los Angeles, CA,
carla_u@alumni.usc.edu
[b] *Conductor, ASTE527 Graduate Space Concept Synthesis Studio,*
Astronautical Engineering Department, Viterbi School of Engineering, Lecturer USC School of Architecture,
University of Southern California, Los Angeles, California 90089,
mthangav@usc.edu
* Corresponding Author

Abstract

The concept architecture presented in this paper is about Creating Human Experience through Food (CHEF) in Space. It is part of promoting Commercial Human Spaceflight Expeditions (CHASE), a USC Fall 2021 team project. The overall plan proposes the early transition of the International Space Station (ISS) operations away from NASA core human spaceflight projects to an university consortium and the private sector. The plan comprises adding private labs experimental and manufacturing modules, and includes a hotel that accommodates space tourists in the future, as mandated by US space policy.

The goal of CHEF is to serve freshly prepared gourmet food that provides space travelers with an exceptional dining experience. It addresses the challenges of creating a more palatable meal, providing nutritious and tasty food, and catering to individual's caloric needs. CHEF strategy tailors to individual's cravings of the day, on-orbit. It proposes a food technology system that prepares, cooks, and serves the food in an automated fashion. The use of a pressure cooker concept is introduced to cook food per the space travelers' request in short turn-around cycle, from order to delivery. A mixture of preserved food, raw ingredients and spices are processed to go into an ISS, space-compliant pressure cooker system that uses solar energy. With the use of existing technologies, such as 3-D printing of food, robotic chef, tele-robot arms, and Astrobees, integrated together, an automated kitchen service is made possible to implement the end-to-end, fresh restaurant-style gourmet food experience.

Because of the US space tourism mandates for ISS, and the Gateway and Artemis mission plan for returning astronauts to the Moon, there is now an economic opportunity to build a robotic kitchen in space that caters to space travelers in the future.

Together with water and breathable air, good nutrition is critical for human spaceflight. CHEF in Space project's goal is to serve gourmet food in their short or long journeys to space. Food is the vital fuel to support humans and it is imperative that their needs are addressed with the highest priority along with crew safety and wellbeing. For any successful and productive human space exploration or space activity, great tasting fresh meals are a prerequisite for the space traveler, especially as we plan endurance-class missions and tours-of-duty lasting months to years to the Moon, Mars and beyond.

Evolving from the ISS, CHEF systems can progress to serve the crew on Gateway and Artemis, followed by endurance-class missions to the Moon, Mars and beyond.

Keywords: Robotic Kitchen, International Space Station, Solar Pressure Cooker, Human Spaceflight

Acronyms/Abbreviations

CHASE – Commercial Human Spaceflight Expeditions
CHEF- Creating Human Experience through Food
CSA – Canadian Space Agency
ISS - International Space Station
LEO – Low Earth Orbit
SPC - Solar Pressure Cooker
NASA-National Aeronautics and Space Administration

1. Introduction

The Artemis mission has motivated further advancements and developments in the human space exploration arena. There has been an increase in private space companies, sprucing up to innovate and produce space products.

NASA and CSA launched the Deep Space Food challenge, calling all food innovators around the world to take on the challenge of developing novel food production technologies that can support long-duration missions. Many food systems on Earth still do not meet established spaceflight requirements. Basic constraints spaceflight face includes safety, weight, size, and variety. The challenge is to fill food need gaps when resupply does not get to the spacecraft in time and improve processing time to create palatable food and variety.[10] This was the major motivation for the CHEF in space project with a goal to provide space travelers an exceptional space dining experience by serving gourmet food while on this space journey. Since US space policy now mandates space tourism to ISS, the issue of providing fine dining to visitors has taken on a high priority.

Historically, the meals that astronauts eat comes pre-packaged. These pre-packaged meals are prepared on Earth to be rehydratable, thermostabilized, irradiated, heated with intermediate moisture, or ready to eat with no heating required.[6] Due to technological constraints, there are limited cooking gadgets in the ISS to microwave oven, convection oven, and hot water to heat or cook the food. The astronauts are also constrained to the well thought out daily menu provided for their journey.[2]

Based on the astronaut's food experience in the ISS, foods taste different in space. There are concerns about the aroma and palatability of the food, consequently affecting food intake and leading to under-consumption. This is evident from the weight loss that astronauts experience during space flight.[1] Based on the conditions that astronauts experience in space, their appetite for certain foods change.

The concept for the CHEF in Space is to create an exceptional dining experience and produce gourmet food that can be tailored to cater individuals' needs on a daily basis. It proposes a food technology that prepares, cooks, and serves the food in an automated fashion, with quick turnaround, from order to delivery. Instead of a set menu for everyone to eat for that day, the use of a space solar pressure cooker (SPC) concept is introduced to cook food per the space traveler's requests in a short period of time.

In this paper, Section 1 provides the background, motivation and an overview of the CHEF concept. Section 2 describes the existing technologies that can be utilized and integrated into the CHEF in Space to create a robotic kitchen. Section 3 illustrates the SPC concept to be introduced in space. Section 4 describes the CHEF in Space Robotic Kitchen module that would be integrated into the ISS, and the end-to-end CHEF in Space experience. Section 5 discusses the opportunities, challenges, and complexities of making this robotic kitchen in space a reality. Section 6 summarizes the CHEF concepts and concludes the motivation for a Robotic Kitchen in space.

1.1 Space Food History[2]

Food is the humans' fuel and therefore a critical factor in any human spaceflight. The list of human spaceflights and its corresponding food packaging is provided below:

- Project Mercury: food included bite-sized cubes, freeze-dried food, semi-liquids in aluminum toothpaste-type tubes.
- Gemini: provided more variety on food and improved food packaging
- Apollo: wetpack or thermostabilized flexible pouch to contain the prepared food was developed.
- Skylab: food tray and food warmer were introduced.
- Space Shuttle: more personalized menus and use of food warmers.
- Space Station: use of convection and conventional ovens and microwave were introduced and are used to this day.

2. Existing Technologies, Research, and Development

There are proven technologies on Earth that can be integrated together to make an automated kitchen in space a reality. These include additive manufacturing, robot chef, tele-robot arms, and Astrobees, to name a few.

2.1 Additive Manufacturing[5]

There are many products in the market that already does 3-dimensional (3-D) printing of food.[8] There are startups and emerging companies that showcased 3-D printing meat, desserts, and entrees with their food printing equipment, allowing for customization without compromising food quality, human health, safety and the environment. It enables more personalization and consistency for intricately designed food, making the food more visually appealing to eat for diners.

2.2 Robot Chef[14]

Moley Robotics, located in the UK, created the world's first robotic kitchen that can cook more than 5,000 recipes. It features a robot arm programmed to emulate a chef's movements on how dishes are cooked. There are now startups from other countries following suit and developing their own kitchen robot systems to cook a more specific cuisine.

2.3 Telerobot[18]

Robotic arms that can be controlled at a distance have been demonstrated in various fields, such as healthcare and manufacturing. This concept can also be applied to food technology in which chefs can control the robotic arms using a pair of gloves to emulate their movements on cooking a meal.

2.1 Astrobees[16]

The Astrobee system is a cube-shaped robot introduced inside the ISS in 2019 to assist astronauts with mundane tasks. With microgravity, the Astrobees float freely and propel themselves through the ISS to execute routine

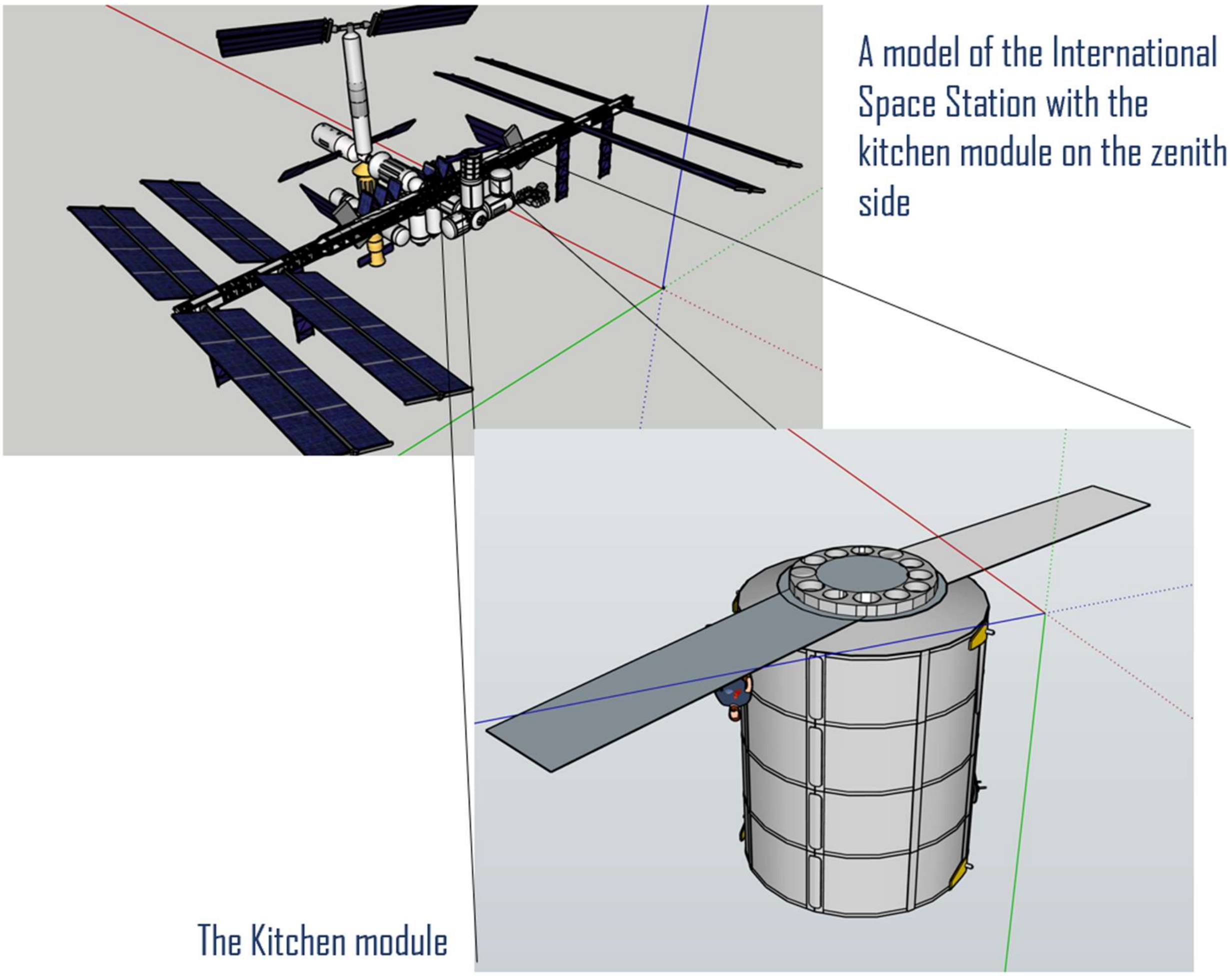

Figure 1: The Kitchen Module retrofitted into the ISS

duties astronauts typically do in addition to conducting experiments and performing complicated activities.[17]

3. Introducing the Solar Pressure Cooker in Space

The ISS Robotic Kitchen module is a proposed addition to the existing ISS infrastructure. The plan is to retrofit the robotic kitchen module on the zenith side of the ISS to obtain as much sunlight (see Figure 1).

The pressure cooker is one of the kitchen gadgets and the focal point of the ISS Robotic Kitchen module. The key feature of the pressure cooker is that it significantly reduces the time to cook food using pressure created by trapped steam. Stews, soups, and other dishes that typically require hours of simmering can be cooked in less than an hour. (see Figure 6 for SPC principle). The Robotic Kitchen concept design features multiple pressure cooker vessels in a revolving cylinder (see Figure 2). It allows redundancy, modularity, and variety. Dishes can be cooked at different times. Each of the pot is independently connected to the power source, thus heat source and settings can vary according to the dish being cooked.

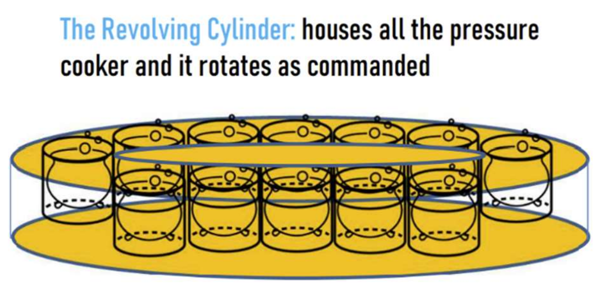

Figure 2: The multi-pressure cooker concept in a revolving cylinder

4. The ISS Solar Pressure Cooker (SPC)

The ISS orbits the Earth every 90 minutes. The temperature varies from 121ºC during the sunlit half of the orbit to -157ºC while transiting the night-side. It is possible to use ambient solar energy to operate the

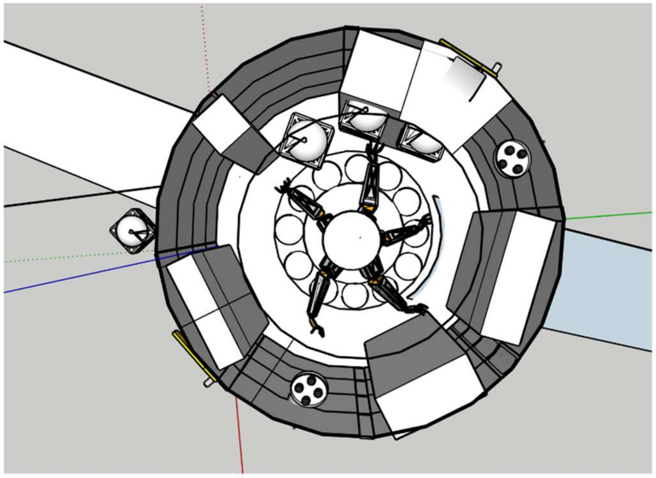
Figure 4: Inside View of the Robotic Kitchen Module

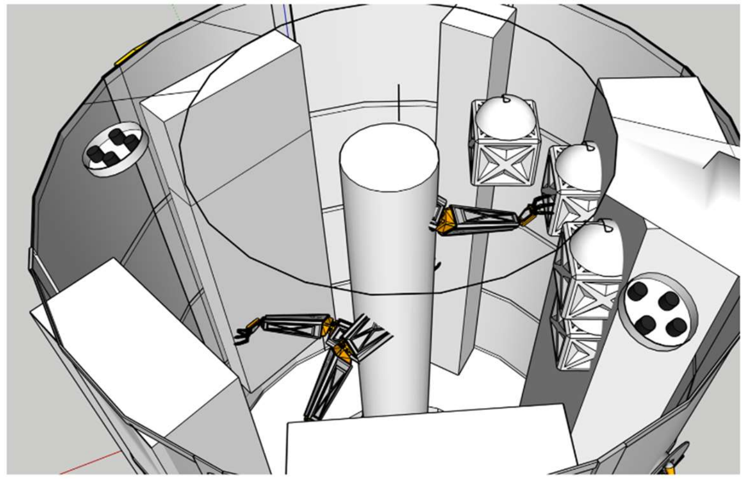
Figure 3: Angled Inside View of the Robotic Kitchen Module

pressure cooker. It is also possible to employ the CHEF in Space system to freshly prepare a variety of cold desserts like ice cream, mousse and sorbets during the night-side transit. (Figure 7 shows schematic of Earth-based solar pressure cooker). Alternate configurations of the ISS SPC are being studied that include heliostat steering and solar concentrator system versions as well as heat pipes to deliver a range of temperatures for the CHEF system during ISS orbit.

5. Robotic Kitchen Module Design and Process

In a traditional commercial kitchen, there are different stations set up to execute specific tasks and create the dish. The same concept is designed in the Robotic Kitchen in which different modules represent the kitchen stations performing specific tasks, such as the food storage, food preparation, cooking, temperature control, and cleaning, that serves in the end-to-end food creation process.

An inside view of the Kitchen module is illustrated in the Figure 3 and Figure 4. The food creation is orchestrated through the robot arm module.

4.1 Kitchen Modules

- *Environmental Control Module:* controls the temperature, humidity, and pressure in the kitchen module

- *Command & Control Module:* the brain of the kitchen module that orchestrates the dish preparation process

- *Food Storage Module:* stores the fresh food, preserved food, frozen food, sauces, and spices

- *Revolving Pressure Cooker Module:* houses the 12 pressure cookers and rotates as ingredients are put in for cooking and cooked food is taken out.

- *Heating and Food Prep Station:* houses the gadgets to process fresh ingredients, such as slice, grate, cut, peel, juice, etc., and use the convection oven, microwave oven, or hot water as another means to cook food

- *Dish Clean and Prep Station:* transfers food from pressure cookers into a dish, provides a place for serving dishes, holds prepared dishes, and warms the food as it waits for it to be transferred to an available Astrobee

- *Astrobee Station:* this is where the Astrobee Food Attendants charge itself and where the robot arms load the plated food to be delivered

4.2 End-to-End Gourmet Food Experience

The McDonald's Speedee Service System is applied to execute the end-to-end gourmet food creation process. The Robot arms in the module help execute the production line that creates a variety of dishes.

The experience starts with a robot server using an Astrobee dedicated to perform the task of taking orders from space travelers. The menu for the day is presented based on the ingredients available. The space travelers make their selections and their inputs are processed by the robotic kitchen. The robotic kitchen prepares the ingredients and cooks the dish using the pressure cooker.

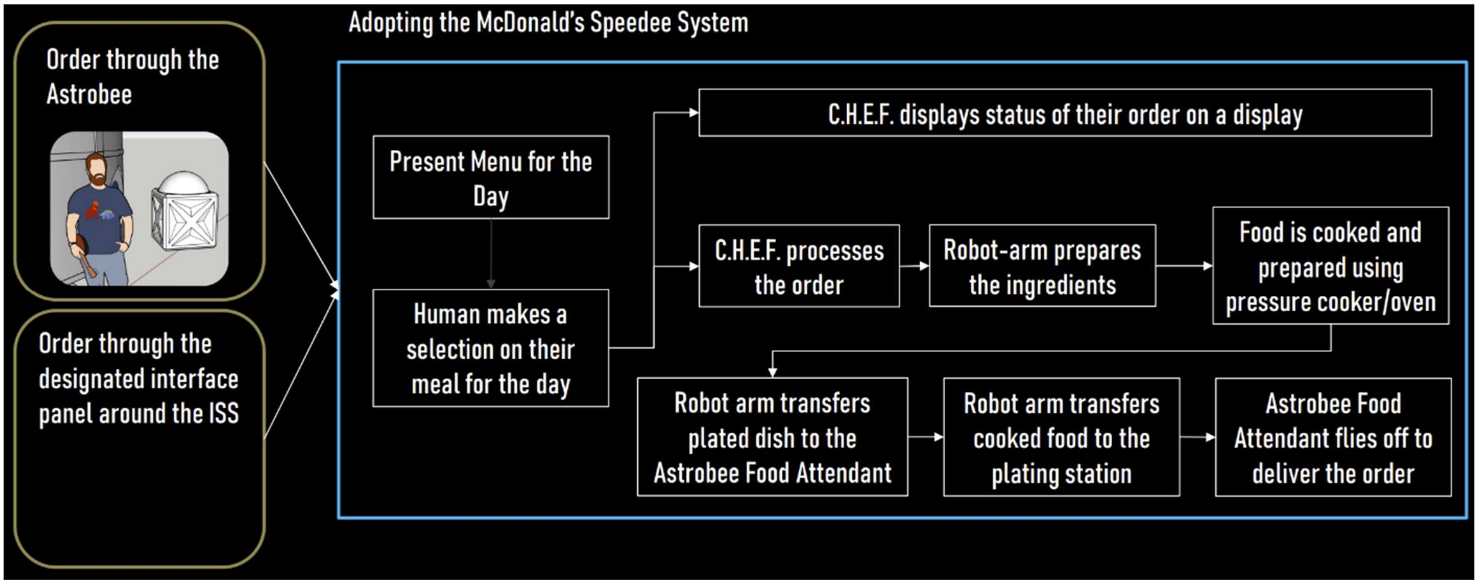

Figure 5: The End-to-End Flow of the CHEF in Space

The dish is plated and moved to the Astrobee module. The Astrobee then floats off to deliver the food to the designated space traveler or the area where space travelers dine together.

6. CHEF Opportunities, Challenges, and Complexities

The opportunities that the Robotic Kitchen module offers are scalability as it can prepare food for as little as one person or as much as the maximum number of people on the space vehicle. It offers other cooking alternatives, such as the use of microwave or convection oven, that already exists in the ISS. The kitchen modules offer a modular architecture and allows for evolution and growth. With the use of fresh ingredients, the robotic kitchen cooks nutritious food and can make it palatable by creating intricate designs on the dish.

The major constraints of the robotic kitchen are the weight restrictions when launching the module from earth and sanitation as cooking food can get messy. Cleaning and sanitizing utensils, dishes, pots and pans are one of the necessary functions in a kitchen and therefore is heavily considered in the food service operations. In order to maintain the health and safety of the space travelers, sanitation is crucial.

There are complexities in integrating a fully automated robotic kitchen. There are still unknowns on how a pressure cooker would function in a microgravity environment. Will it have the same cooking behavior on Earth? What are the emergent behaviors with cooking in space? These questions may be answered by conducting experiments aboard the ISS.

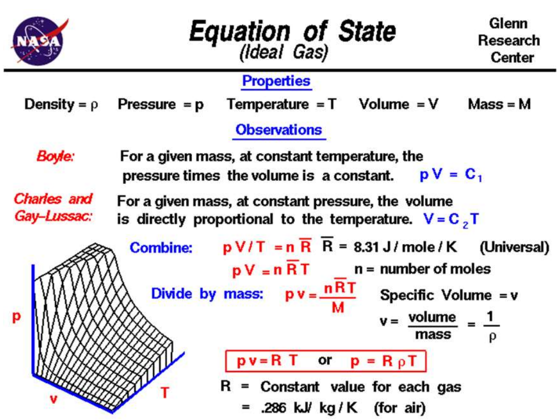

Figure 6: Equation of State

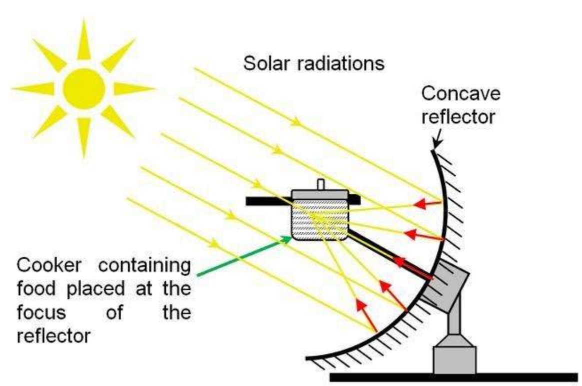

Figure 7: Schematic of Solar Pressure Cooker

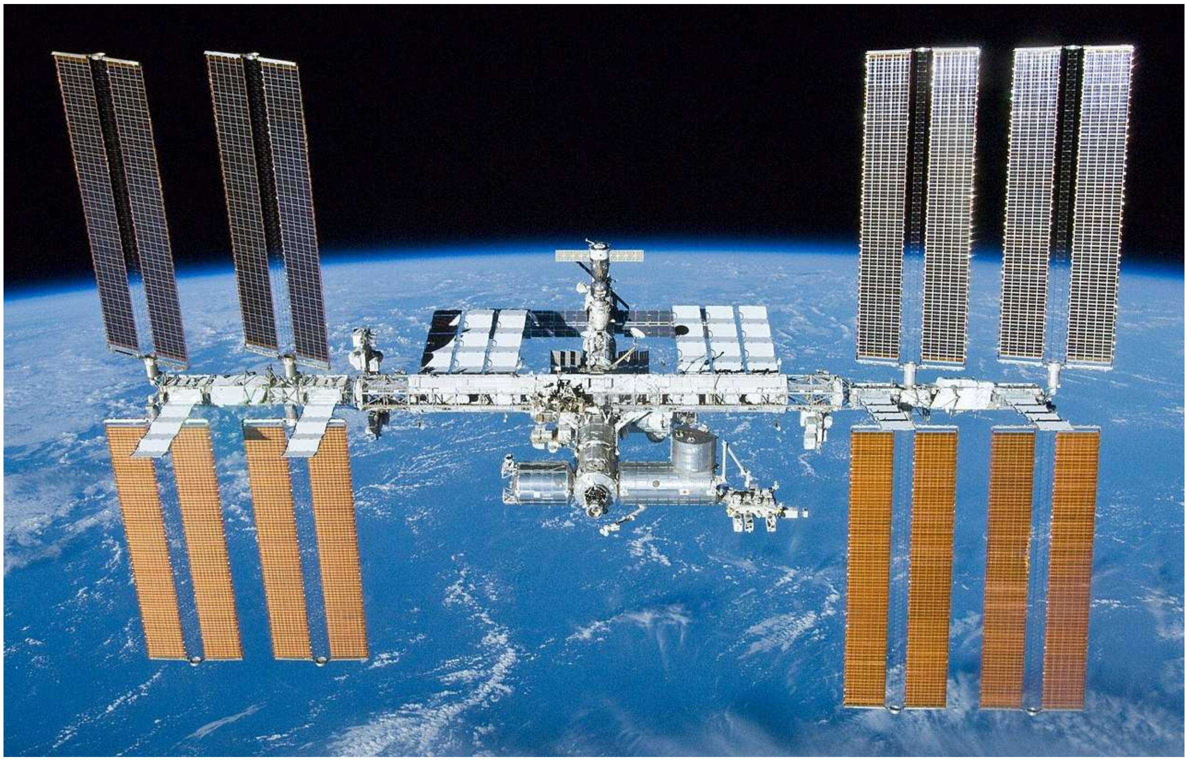

Figure 8: Evolving from the ISS, CHEF systems can progress to serve the crew on Gateway and Artemis, followed by endurance-class missions to the Moon, Mars and beyond[credit NASA]

7. Conclusion

Space tourism has become a reality as it is now mandated by US policy to be aboard the ISS. A handful of companies such as World View, Space X, Virgin Galactic and Blue Origin have found ways to offer people varying experience of space. There are people who dreamed of traveling to space and that dream has become possible, thanks to the innovative technologies and companies who make it happen for civilians who are not professional astronauts.[9]

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Food is the vital fuel to support humans and it is imperative that their needs are addressed with the highest priority along with crew safety and wellbeing. For any successful and productive human space exploration or space activity, great tasting fresh meals are a prerequisite for the space traveler, especially as we plan endurance-class missions and tours-of-duty lasting months to years to the Moon, Mars and beyond.

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