

1. (6 pts). **Humans to Mars** – Let’s pursue the questions posed by Professor Jakosky during his class presentation and other issues about exploration of Mars.
- a. Compare and contrast the characteristics of the Moon to those of Mars. Include in your analysis mass, gravity, atmosphere, orbital characteristics, geology, and water. Discuss how the Moon might serve as an analog to Mars and help us learn how to eventually explore the Martian surface with humans.

	Moon	Mars
Mass	7.3×10^{22} kg	6.4×10^{23} kg
Gravity	1.62 m/s^2 (0.17 g_{Earth})	3.72 m/s^2 (0.38 g_{Earth})
Atmosphere	The Moon has an extremely tenuous atmosphere that most purposes is essentially nonexistent.	The atmosphere of Mars is about 100 times thinner than Earth’s and is primarily composed of carbon dioxide. It also has significant amounts of Nitrogen and Argon, as well as trace levels of other atoms/molecules.
Orbital Characteristics	The Moon completes one orbit around the Earth every 27 Earth days. The Moon is tidally locked with the Earth, meaning that the same side (i.e., the nearside) always faces the Earth.	The orbit of Mars has a semimajor axis of 1.5 AU and completes one orbit around the sun every 687 Earth days. Very eccentric orbit compared to Moon.
Geology	The Moon is composed of two basic types of regions: Maria, smooth, low-lying regions composed of volcanic basalt, and the highlands, which are hillier, older, and heavily cratered. The similarity of isotopic ratios in lunar and terrestrial samples likely points to the giant-impact hypothesis that posits that the Moon formed through a collision between the proto-Earth and another planetary body.	Mars is a differentiated planet with a metallic core and a mantle and crust. Mars’ red appearance is due to the presence of iron oxide (i.e., rust). The surface of Mars shows the presence of significant volcanic activity, signs that liquid water was previously present.
Water	Water exists on the surface of the Moon primarily in the form of ice in permanently shadowed regions in craters near the lunar poles.	Water is present on Mars in the North polar ice cap. There are also trace amounts of water in the Martian atmosphere.

Initially, the Moon can serve as a testing ground for the technology needed for a sustained human presence on a planetary body other than the Earth. Although the technology may need to be modified before a mission to Mars, key elements such as the radiation and space environment will be the same. The Moon can also be used to experiment with how best to utilize robotic assets during a human mission. While on the surface of Mars, astronauts' times will be a precious commodity. How to use this time in the most efficient manner can be perfected during lunar missions before humans set foot on Mars.

- b. How are the Perseverance and Curiosity rovers and the MAVEN mission preparing us for eventual human exploration of Mars? Describe what we are learning from these three missions.

Both the Perseverance and Curiosity rovers are providing direct measurements of the conditions and geology of the Martian surface. Curiosity also measured the radiation environment on its way to Mars, which is important data for a human mission. The Mars Atmosphere and Volatile Evolution (MAVEN) mission in orbit of Mars is studying the atmosphere of Mars, specifically how the atmosphere has deteriorated over time. Perhaps the most alluring reason to study Mars is to determine if Mars was ever a habitable environment for life. Both Curiosity and MAVEN may provide clues as to the conditions and environment on Mars before a significant portion of its atmosphere was lost. They may help us better determine what and where to study Mars once astronauts set foot on the surface.

- c. Is a human Mars mission technically feasible? Do a little research online to justify your answer.

Yes, a human mission to Mars is technologically feasible, but would require a huge investment. One of the main concerns regarding a crewed Martian mission is the radiation exposure of astronauts during the long journey. However, recent research indicates that a mission of less than 4 years during solar maximum (which deflects extragalactic energetic particles) would limit radiation exposure to non-lethal levels for some (<https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2021SW002749>). While the technology would need to be adapted to a crewed capsule, numerous robotic missions have demonstrated that landing on the Martian surface can be done safely.

2. (6 pts). The Decadal Surveys & Roadmaps

- a. Why do scientists undertake a “decadal survey” once every ten years? What are the goals of these surveys?

The decadal survey is a chance for the scientific community to discuss how to prioritize their studies for the upcoming decade. The purpose of the decadal survey is to identify the most interesting scientific questions in the field and to determine and plan the infrastructure needed to answer them. The result is that funding agencies such as the federal government can allocate funding appropriately. This ensures that the highest priority missions or studies are given sufficient resources even when funding may be limited.

- b. Pick **ONE** of following that we discussed in class: the Astrophysics or Planetary Sciences/Astrobiology or the Heliophysics Decadal reports (see full reports on class website). Describe

- i. At least two science goals for that Decadal.

I will describe science goals from the astrophysics decadal survey. One science goal, which the report generally refers to as “pathways to habitable worlds,” involves determining whether habitable planets, that may hold life, exist outside of Earth. The report recommends continued exoplanets surveys and the development of diagnostic tools to better characterize the atmospheres and surfaces of exoplanets in order to accomplish this goal.

Another science goal, referred to as “new windows on the dynamic universe,” seeks to probe the “formation, evolution, and nature” of compact objects such as black holes and neutron star through multi-messenger astronomy. Multi-messenger astronomy refers to using observational probes beyond just the electromagnetic spectrum, such as gravitational waves or high-energy particles. Part of this goal involves investigating how matter behaves under extreme conditions that cannot be replicated in a laboratory setting, such as the extreme gravity present near black holes.

- ii. Two space missions advocated by the Decadal that will address one or more of the science goals that you identified in (i).

One space mission recommended by the decadal survey is a 6-meter space telescope designed for observations at ultraviolet, visible, and infrared wavelengths. The experiment is essentially a combination of LUVOIR and HabEx, two previous mission concepts. This telescope would be particularly well suited to the characterization of potentially habitable exoplanets and would contribute significantly to the “pathways to habitable worlds” science area.

Also contributing to the search for habitable exoplanets is the Nancy Grace Roman space telescope, an infrared observatory recommended by the decadal survey. A coronagraph will allow Roman to perform direct imaging of some exoplanets, providing images and spectra. Roman will also have the capability to investigate dark energy and cosmic acceleration through phenomena such as weak gravitational lensing.

- c. Review the Decadal Survey that you chose in (b) in relation to the proposed FY22 NASA budget that we discussed earlier in class (https://www.nasa.gov/sites/default/files/atoms/files/fy23_nasa_budget_request_summary.pdf). Does this budget address the science priorities of the Decadal Surveys in your opinion?

The science portion of NASA’s budget allocates significant funding to currently operational facilities such as James Webb, Hubble, and Chandra X-ray observatory. Though these are not necessarily “recommended” by the report since they have already been built, they are still very important to many of the science goals and priorities given in the report. The science budget also contains \$482 million in FY23 for development of the Roman space telescope, one of the large facilities recommended by the decadal survey and which would launch later this decade. Beyond this, however, it seems that not all the priorities listed in the report may receive sufficient funding in the current NASA budget. For example, the LUVOIR-HabEx hybrid facility would likely cost 10s of billions to construct. It is difficult to see in the current budget where this money would come from. Although there exist other organizations that may be able to provide some funding for astrophysics projects, few can devote enough resources to support these large missions. It seems unlikely that all the goals of the decadal survey will be able to be addressed, at least at the level outlined in the report.

3. (6 pts). Authorization and Appropriation

- a. What is the purpose of Authorization bills passed by the Congress?

An authorization bill is a type of legislation that authorizes (i.e., recommends but without actual funding allocated) the activities that are performed by the agencies that are under the purview of the federal government. Passing an authorization bill gives the programs that are authorized the ability to exist and operate, as well as establishes the terms under which the program may operate. Authorization bills are separate from appropriations bills, which provide the funding needed to carry out the activities.

- b. Review the recently passed NASA Reauthorization Bill

(https://beyer.house.gov/uploadedfiles/nasa_authorization_in_chips_2-pager.pdf).

Describe TWO of the highlights of this bill in your opinion.

The first noteworthy provision of the bill is that it creates a “Moon to Mars office” as well as a “Moon to Mars program.” The establishment of these two entities is important because they relate directly to NASA’s stated goal of utilizing the Moon and the Artemis program as a proving ground for future human missions to Mars. Although the current NASA budget still is likely insufficient to support the realization of a human mission to Mars, the creation of a specific Moon to Mars program is in line with the stated goals of the agency.

The other highlight of the authorization bill is that it specifically directs NASA to continue development of the Nancy Grace Roman Space Telescope. This telescope, formerly known as WFIRST, was recommended as a top priority in the 2010 astrophysics decadal survey. After also being recommended for funding by the 2020 astrophysics decadal survey, the authorization bill direct NASA to continue its development. This shows the importance of the decadal surveys and how the top priorities as determined by the decadal surveys are extremely influential in space policy and the projects that NASA undertakes.

- c. Review NASA’s proposed FY22 budget that was discussed in class (one pager handed out and also on class website & see question #2). In your judgment what is included and what is missing from NASA’s budget in order to meet goals described in NASA’s 2022 Reauthorization Act.

Many of the topic addressed in the reauthorization bill are adequately represented in the budget. For example, continued operation of the ISS, development of the ROMAN space telescope, and STEM engagement efforts are both discussed in the bill and receive funding in the budget that appears to be commensurate with their importance. However, while the reauthorization bill heavily emphasizes the goal of a human mission to Mars immediately following human missions to the Moon, it does not appear that there is enough money allocated in the budget to accomplish this goal. While the reauthorization bill may create a Moon to Mars office with a director and responsibilities, the level of funding is ultimately what will determine whether Moon to Mars is an attainable goal.

4. (8 pts). Your Business Plan for a space start-up company.

In class, we had presentations from the leaders of two space start-up companies. Now, it is your turn to describe an idea to start your own company! You need to begin by writing a brief **Business Plan** for your company. A business plan is a roadmap for business success. This document projects 3-5 years ahead and outlines the route a company intends to take to grow revenues/profits. It needs to include the following (a brief paragraph for each):

- a. *Company Description* – what you do sell, build, design, etc.?
- b. *Competitors* – how are you different from existing companies?
- c. *Market Analysis* – who are your customers?
- d. *People* – what talents, experience, education are needed for your key employees?

Company Description - My startup company will be focused on in-situ resource utilization on the Moon, particularly at the South Pole, where permanently shadowed craters hold precious resources, including water-ice and other volatiles. Rather than perform the resource extraction ourselves, my company will create resource assessments, in which we estimate the quantities and locations of potentially accessible resources on the lunar surface. These assessments will be made with a combination of in-situ and remote sensing observations to construct a better picture of where the most promising locations for ISRU (in-situ resource extraction) are located.

Competitors - While there are several companies devoted to lunar ISRU efforts, they are focused on developing technologies for extracting and utilizing the resources. One such company, Lunar Outpost based in Golden, CO, is developing several different technologies including advanced robotics and artificial intelligence software to best extract resources from the lunar surface. Once these companies can transport their infrastructure to the Moon, they need to know the best locations for performing their operations.

Market Analysis - It is at this point that my company can provide a service to these other lunar resource businesses by helping them determine the optimal locations for whatever goal they want to accomplish. Instead of competing with these other businesses, we can help any business accomplish their goals more efficiently. Beyond just other businesses, we can also work with NASA or other national space programs to identify the best locations for resource collection experiments.

People - This company will require a number of employees who are trained in statistical analysis of resource assessment observations. Resource assessment is common in more established business areas here on Earth such as fossil fuel or mineral extraction. Although the process will no doubt be different for the Moon, we can still utilize the expertise from these areas. We will also likely require in-situ measurements to confirm and extend the remote sensing observations. Performing these measurements (likely through robotics on the lunar surface) will require engineers that are familiar with lunar surface operations.