Astronomy 4800 Homework #1 Solutions

1. **(6 pts). Why should we explore space?** Let's take three of the common arguments for exploring space noted below. Do a little research online (be sure to cite references!) and argue why these make good reasons (or not!) to explore space.
    a. We are in a new space race with China. Our national security depends upon securing the "high ground".
    Example Response:
    The Outer Space Treaty sets boundaries on how governments should conduct themselves in space exploration, but there is no real mechanism for enforcing its provisions. Although Article IV states that space exploration must be for "peaceful purposes" and explicitly outlaws nuclear weapons, we should not take it for granted that all governments, even those that signed the treaty (including China), will always choose to obey it. The government of China has already pushed the envelope of the norms of space exploration by allowing rocket debris to fall to Earth on an unknown and uncontrolled trajectory (*New York Times*) and developing and using anti-satellite weapons (*BBC News*). With recent Chinese interest in Lunar exploration with the Chang'e 4 rover and Queqiao relay satellite, the United States cannot afford to get left behind in a new era of space exploration.
    b. Space is the next Silicon Valley. A "space economy" will create new companies and new opportunities for entrepreneurs.
    Example Response:
    There is clearly already commercial interest in space. In the last 15 years, commercial companies have tripled the amount spent on space activities, from $110 billion in 2005 to $357 billion in 2020 and this is only expected to increase in the future (*Washington Post*). There are numerous entrepreneurial opportunities in space from tourism, to resource mining, to infrastructure for science and exploration. By exploring the Moon and beyond (with both crewed and uncrewed missions), we are opening a new frontier with huge potential economic benefits.
    c. Space inspires the next generation to study the STEM fields (science, technology, engineering, math) and will result in growing U.S. technology infrastructure.
    Example Response:
    The public has always been captivated by space exploration (see the popularity of Carl Sagan, Neil Degrasse Tyson, and the amount of people wearing NASA T-shirts on any given day). However, the latest Elementary and Secondary STEM Education Report from the National Science Foundation shows that the U.S. is lagging other countries in terms of student performance in science and mathematics. While there are likely a wide number of causes that contribute to this underperformance, getting people (particularly students) excited about the possibilities enabled by space exploration is likely to improve interest and performance in STEM. These students may then go on to make careers in STEM that may not have otherwise, leading to a more diverse and educated workforce.

2. **(4 pts).** The NASA Science Mission Directorate (SMD) is divided into four discipline areas: Earth Science, Planetary Science, Heliophysics (study of the Sun and space weather), and Astrophysics. Go to NASA's *Science 2020-2024: A Vision for Scientific*

Excellence at: https://science.nasa.gov/science-pink/s3fs-public/atoms/files/2020-2024_Science.pdf and read about the scientific goals and objectives, along with the current missions underway.

a. Briefly describe the four priorities that NASA currently maintains for science. Elaborate on two that you think are most important and describe why.

Example Response:

NASA's first priority is exploration and scientific discovery, which involves efforts to discover the secrets of the universe, search for life, and other important questions. The second priority is innovation, which is achieved through the development of new technologies and strategies to answer research questions. Third is interconnectivity and partnerships, which recognizes the importance of collaboration with a wide variety of people and organizations. Finally, inspiration involves encouraging and developing future leaders through engagement and public outreach. In my opinion, exploration and scientific discovery as well as inspiration are the two most important goals because they are closely aligned with public perception of NASA. Through the Apollo lunar landings and numerous scientific missions such as the Hubble Space Telescope, NASA has always been a beacon of both inspiration and scientific discovery.

b. Then, compare and contrast today's priorities with goals described in the paper *Introduction to Outer Space* (class website for Aug. 31) from 1958. How are things similar and how are they different from what was described to President Eisenhower?

Example Response:

The goals outlined in Introduction to Outer Space are exploration, development of technology, national prestige, and advancement of scientific knowledge. These goals are quite similar to NASA's current stated priorities with the exception of national prestige. With the context of the Soviet Union and the space race, it makes sense that NASA would be much more focused on national prestige during Eisenhower's presidency. Now, this has been replaced with a focus on (global) collaboration.

3. **(4 pts).** In class, we showed a graph of how government R&D funding as a share of GDP has declined over the past 60 years while industry funding has increased (see notes from Aug. 26 lecture).

a. Do a little research and discuss why you believe these funding trends developed as they did? Make sure to discuss the differences in funding and expected outcomes of R&D investments between government agencies and industry.

Example Response:

Ultimately, the responsibility for funding levels falls on those who construct and approve the budgets. For the federal government, this is the President and congress. For industry, it is the executives at a given company. Clearly those two groups have come to different conclusions regarding the relative importance of funding R&D. There are likely a myriad of reasons why government funding has consistently declined over the last few decade, including gridlock (e.g. shutdowns and difficulty passing budgets) or shifting political priorities to other subjects. R&D funding is not likely significant issue to most voters, so it may be easy for congress people to neglect it without damaging their electoral prospects. Additionally, government funding for R&D is often devoted to basic rather than applied research. While basic research still produces innovation and advances knowledge, it is often more abstract and does not always address a practical problem or application. Funding for basic research may be hard to justify to taxpayers without a direct application or product to show for it.

On the other hand, industry executives have clearly concluded that increases in R&D funding are beneficial for private companies. Unlike government funding, this R&D funding is generally aimed at developing (the D in R&D) or improving products that can then be sold for profit. In an economy driven more and more by new technologies, it seems likely that R&D funding is essential for companies to stay ahead of competitors.

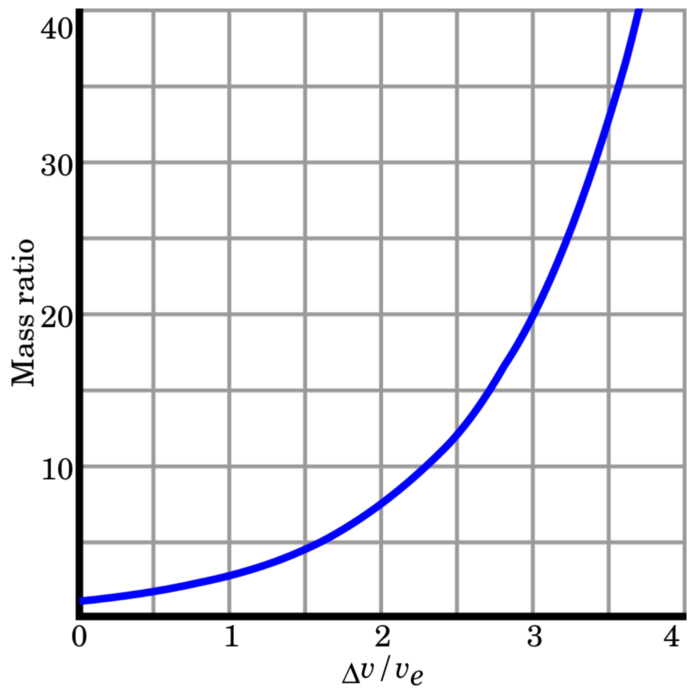
b. One of the stakeholders for science policy that we identified is "the Public". Discuss why the public/taxpayer should be invested in the development of science policy on the federal level.

Example Response:

Perhaps the most direct reason that the public should have an interest in federal science policy is that the public funds scientific research through taxes. Citizens should want their tax dollars to be spent in a manner that is efficient and maximizes their impact. Science policy involves deciding how tax money is allocated in terms of which projects or subject areas are deemed most important and what institutions and researchers are awarded funding. Scientific research can also have significant direct effects on the lives and well-being of the general public. Covid-19 vaccines were developed in part due to taxpayer funding from the federal government. Federally funded research at the National Center for Atmospheric Research (NCAR) here in Boulder helps prepare for and mitigate the effects of natural disasters such as hurricanes, droughts, and more. The public naturally should be invested in these issues that have such a large effect on nearly the entire population.

4. **(6 pts). The Rocket Equation.** Let's explore the requirements on a rocket needed to launch from the Earth and from the Moon. This equation was first developed by the Russian

scientist Tsiolkovsky in the early 20th century. Beginning with Newton's third law of motion, Tsiolkovsky derived the "rocket equation" which allows us to calculate the fraction of the rocket's initial mass that must be in fuel to achieve a velocity ΔV (called delta V) for a rocket with an exhaust velocity of v_e. The figure to the right is a plot of the results from this equation where Mass Ratio is the ratio of the initial rocket mass (called the "wet" mass that includes the rocket superstructure, the payload, and the fuel) to the final mass (or "dry" mass after the fuel is exhausted).



a. To go to the Moon, a rocket needs to essentially achieve escape velocity from the Earth. The escape velocity from the Earth is ΔV=11.2 km/sec. Let's assume that our rocket has an exhaust velocity v_e=4.5 km/sec. From the plot above, determine the Mass Ratio needed to escape Earth. Use a little algebra to rearrange the Mass Ratio and calculate the fraction of the initial rocket mass that must be fuel.

Using the values given in the problem, $\frac{\Delta V}{v_e} = \frac{11.2}{4.5} \approx 2.5$. using the graph above, this corresponds to a mass ratio of approximately 10. Let m_p be the mass of the payload (i.e., the mass of the rocket with no fuel) and let m_f be the mass of the fuel. The mass ratio is then equivalent to $\frac{m_p+m_f}{m_p}$. We want to find the initial rocket mass that must be dedicated to fuel, or $\frac{m_f}{m_p+m_f}$.

$$\frac{m_p + m_f}{m_p} = 10$$

$$m_p + m_f = 10m_p$$

$$m_f = 9m_p$$

$$\frac{m_f}{m_p + m_f} = \frac{9m_p}{m_p + 9m_p} = \frac{9m_p}{10m_p} = 0.9$$

So, 90% of the initial mass of the rocket must be dedicated to fuel.

b. Let's now do a similar calculation but this time we are going to launch from the Moon. The escape velocity from the Moon is ΔV=2.4 km/sec (which corresponds to the lower gravity that is 1/6th that of Earth). Using the same rocket exhaust velocity as above, calculate the fraction of initial rocket mass that must be in fuel to escape from the Moon.

In this case, $\frac{\Delta V}{v_e} = \frac{2.4}{4.5} \approx 0.5$, which corresponds to a mass ratio of about 2. Doing the same algebra as in part a, we find that $\frac{m_f}{m_p + m_f} = \frac{1}{2}$, so only 50% of the initial mass must be dedicated to fuel to escape from the Moon.

c. What conclusions can you draw regarding the relative economics of bringing materials into space manufactured on Earth versus manufactured on the Moon?

Much less fuel is needed to launch materials into space from the Moon, making it much cheaper than launching materials from the Earth. Therefore, it is economically advantageous to manufacture or mine materials on the Moon.