What Good is Astronomy?

What good is astronomy? How can astronomers justify the support they receive from taxpayers? What benefit does society derive from astronomical research? What is the rate of return on our investment?

These questions are difficult, but not impossible, to answer. The economic benefits of basic scientific research are often realized over the long-term, and it's hard to anticipate what spin-offs may develop as a result of any specific research program.

A purist might refuse even to respond to these questions. What justification does basic research need other than the pursuit of knowledge? What higher achievement can civilization hope to accomplish than the luxury of seeking answers to some of the oldest questions: where did we come from, and what is our place in the universe?

The proper response is probably somewhere in between. The advances in scientific knowledge made possible through basic research have had a definite impact on the standard of living of the average taxpayer. The magnitude of this impact isn't easily quantified, but it probably doesn't need to be. The money that taxpayers contribute to scientific research in some sense obligates the researchers to make their work accessible to the public. A combination of teaching and public outreach provides an adequate return on the investment.

If this doesn't seem reasonable, put this in perspective by looking at exactly how much it costs taxpayers to fund scientific research.

How much does Astronomy cost the taxpayer?

- In 2000, the total federal budget amounted to $1.88 trillion
- Revenue from personal income taxes amounted to $900 billion
- The "non-defense discretionary" portion of the budget amounted to $330 billion
- The National Science Foundation budget was $3.95 billion
- The NSF allocation to the Directorate for Mathematics & Physical Sciences amounted to $754 million
- The MPS allocation to Astronomical Sciences amounted to $122 million

So, even if you assume that the revenue for "non-defense discretionary" comes entirely from personal income taxes, funding astronomy is cheap. Out of every $1000 in revenue from personal income taxes, $365 goes into the non-defense discretionary fund. About $4.35 ends up in the hands of the National Science Foundation. Of this, 83 cents goes to fund all of Mathematics & Physical Sciences. In the end, for every $1000 in taxes only 13 cents ends up funding Astronomical Sciences.

What?, I sometimes ask myself in amazement: Our ancestors walked from East Africa to Novaya Zemlya and Ayers Rock and Patagonia, hunted elephants with stone spearpoints, traversed the polar seas in open boats 7,000 years ago, circumnavigated the Earth propelled by nothing but wind, walked the Moon a decade after entering space—and we're daunted by a voyage to Mars? But then I remind myself of the avoidable human suffering on Earth, how a few dollars can save the life of a child dying from dehydration, how many children we could save for the cost of a trip to Mars—and for the moment I change my mind. Is it unworthy to stay at home, or unworthy to go? Or have I posed a false dichotomy? Isn't it possible to make a better life for everyone on Earth *and* to reach for the planets and the stars?

— Carl Sagan, in "Pale Blue Dot"

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This question typically arises during debates regarding whether a government should spend money on astronomy. There are both pratical and philosophical reasons that the study of astronomy is important.

On the practical side...

Astronomical theories and observations test our fundamental theories, on which our technology is based. Astronomy makes it possible for us to study phenomena at scales of size, mass, distance, density, temperature, etc., and especially on TIME scales that are not possible to reproduce in the laboratory. Sometimes the most stringent tests of those theories can only come from astronomical phenomena. It must be understood that these theories influence us even if they don't tell us that we can invent new things, because they can tell us that we can't do certain things. Effort spent on astronomy can prevent effort wasted trying to come up with antigravity, for instance.

Astronomy provided the fundamental standard of time until it was superseded by atomic clocks in 1967. Even today, astronomical techniques are needed to determine the orientation of the Earth in space, e.g., <URL:http://www.usno.navy.mil/>. This has military applications but is also needed by anyone who uses the Global Positioning System (GPS). Furthermore, it may be that millisecond pulsars can provide an even more stable clock over longer time scales than can atomic clocks.

Closely related is navigation. Until relatively recently (post-WW II) celestial navigation was the ONLY way in which ships and aircraft could determine their position at sea. Indeed, the existence of navigation satellite systems today depends heavily on the lessons learned from aspects of astronomy such as celestial mechanics and geodesy. Even today, in the UK, RAF crews and RN officers need to learn the rudiments of celestial navigation for emergency purposes; until the late 1990s so did US Naval officers.

Astronomical phenomena have been important in Earth's history. Asteroid impacts have had major effects on the history of life, in particular contributing to the extinction of the dinosaurs and setting the stage for mammals. The Tunguska impact in 1908 would have had a far greater effect if it had occurred over London or Paris as opposed to Siberia.

The debate over the magnitude, effect, and cost of greenhouse warming is motivated, in part, by research on Venus. Astronomy has prompted study of the Earth's climate in other ways as well. The study of the atmospheres of other planets has helped to test and refine models of the Earth's atmosphere. The Sun was fainter in the past, an important constraint on the history of the climate and life. Understanding how the Earth's climate responded to a fainter Sun is important for evolution and for the progress of climate modelling. More generally, there is weak evidence that solar activity influences climate changes (e.g., variations in sunspot cycle, the Maunder minimum, and the Little Ice Age) and therefore is important in the greenhouse warming debate. (This is by no means proven by current evidence but *may* prove to be important.)

The element helium was discovered (in a real sense) and named, not by chemists, but by astronomers. In addition to making many birthday parties more festive, liquid helium is useful for many low-temperature applications.

Solar activity affects power-grids and communications (and space travel). Prediction is therefore important, indeed is funded by the U.S. Air Force.

Many advances in medical imaging are due to astronomy. Even the simple technique that astronomers used for decades, of baking or otherwise sensitizing photographic materials, was slow to catch on in medical circles until astronomers pointed out that it could reduce the required x-ray dose by more than a factor of 2. Many of those now involved in some of the most advanced developments of medical imaging and imaging in forensics were trained as astronomers where they learned the basic techniques and saw ways to apply them. More recently, image reconstruction of the flawwed Hubble images led to earlier detection of tumors in mammograms (see back issues of Physics Today).

While we don't yet have a good method for predicting earthquakes, the techniques of Very Long Baseline Interferometry are used routinely to measure ground motion.

Interferometry has also led to the development of Synthetic Aperture Radar. Today SAR is used for earth remote sensing. Applications include mapping sea ice (safety of ships, weather forecasting) and ocean waves (ditto), resource location, agricultural development and status checks.

Jules Verne would never have written "From the Earth to the Moon" without astronomy. Astronomy helped spawn science fiction, now an important component of many publishing houses and film studio productions.

There has been a complex interplay between scientific, military, and civil users, but astronomy has played an important role in the development of such things as security X-ray systems (like those at airports), electro-optics sensors (security cameras, consumer video cameras, CCDs, etc.), and military surveillance technology (like spy satellites).

On the philosophical side...

Perhaps the most important aspect of being human is our ability to acquire knowledge about the Universe. Astronomy provides the best measure of our place in the Universe.

In this century, the ability of astronomy to test General Relativity led directly to Karl Popper's distinction between science and pseudo-science and from there to the way intellectuals (at least) look at science. Astronomy's support of modern physics (such as quantum mechanics) in this century had have important influences on general philosphical and intellectual trends. The "Earthrise" photo, of the Earth rising over the Moon's horizon, from an Apollo mission is often credited as being partially responsible for driving environmental and "save the planet" impulses.

In previous centuries, astronomy led to Copernicanism and subsequent "Principle of Mediocrity" developments---that the Earth, and by extension, humans, is not at the center of the Universe. Eliminating geo- and human-centred perspectives was a major philosophical leap. Astronomy's support of a mechanistic universe in the 19th century had important influences on general philosphical and intellectual trends.

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In general, but certainly more vaguely, the last century of astronomy
has provided many supports to the view that the scientific method is
capable of answering many questions and that naturalistic thinking can
explain the world.  Thus, scientists can answer many creation
questions (e.g., where metals come from, why the Sun shines, why there
are planets).
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Why Do Astronomy?

Or, What do we get for our tax money?

By Dave Finley
National Radio Astronomy Observatory

The purpose of the VLA, the VLBA and of NRAO is to do fundamental research on the nature of the universe in which we live. This research seeks to answer some of the biggest questions we can ask, such as how did the universe begin (or did it begin), how big is it, how old is it, and how will it end (or will it end)? As the science that provides the framework knowledge of where we, and the planet on which we live, fit into the environment of the universe, astronomy is a vital part of the culture of all mankind. A person deprived of the broad outlines of astronomical knowledge is as culturally handicapped as one never exposed to history, literature, music or art. As astronomers communicate new discoveries about the universe, they enrich the intellectual lives of millions.

From the dawn of civilization, astronomy has provided important stepping stones for human progress. Our calendar and system of timekeeping came from astronomy. Much of today's mathematics is the result of astronomical research. Trigonometry was invented by Hipparchus, a Greek astronomer. The adoption of logarithms was driven by the needs of astronomical calculations. The calculus, the basis of all modern science and engineering, was invented by Sir Issac Newton for astronomical calculations. Astronomy provided the navigational techniques that allowed sailors and aviators to explore our planet (and today allow spacecraft to explore our solar system). Astronomy's appetite for computational power drove the development of many of the earliest electronic computers. The space age, which brought us the communication and weather satellites upon which we depend each day, would have been impossible without the fundamental knowledge of gravity and orbits discovered by astronomers. Radio astronomers led the development of low-noise radio receivers that made possible the satellite communications industry. Image-processing techniques developed by astronomers now are part of the medical imaging systems that allow non-invasive examination of patients' internal organs. At today's observatories, the needs of astronomers for better instruments continue to drive developments in such diverse fields as electronics, mechanical engineering, and computer science.

Astronomy has much yet to contribute to human knowledge and progress. From the airplane to the transistor, from radio to lasers, the developments of the Twentieth Century were based on fundamental knowledge of the physics of matter and energy. Astronomy offers scientists from a wide range of backgrounds with a nearly infinite variety of cosmic "laboratories" for observing physical phenomena. It is unlikely that any laboratory on Earth will ever produce matter as dense as that of a neutron star, temperatures as hot as those inside a supernova, or gravity as strong as that of a black hole. Yet, astronomers can study the physics of such extreme conditions routinely with instruments such as the VLA and VLBA. Closer to home, the VLBA is a primary instrument providing valuable data on the drift of Earth's continents and the mechanisms of global climate.

What will this yield? It is the nature of basic research that we can't predict what will come of this work, except that we probably will be surprised. When Kepler and Newton labored to develop the science of orbital mechanics, they weren't thinking of weather satellites or CNN.

Finally, astronomy performs an important educational service for our nation. As an exciting, visual science easily accessible to amateur observers, astronomy stirs scientific curiosity in thousands of young people every year. These young people soon learn that astronomy involves nearly the whole range of the physical sciences, including mathematics, physics, chemistry, geology, engineering and computer science. Many professional scientists in these and other fields first became interested in their profession through astronomy. In today's world marketplace, a competitive nation needs for its entire population, not just its scientists, to have a basic level of scientific literacy. Astronomy, by providing the excitement of new knowledge about the fascinating variety of strange objects in the universe, can help communicate much basic science to all our people.

In sum, astronomy has been a cornerstone of technological progress throughout history, has much to contribute in the future, and offers all humans a fundamental sense of our place in an unimaginably vast and exciting universe.

some disaster. The only perfectly safe mission is the one that never gets launched.

The failure of nerve also involves intellectual timidity. Such fear is often expressed in terms of worry about the costs of space exploration. "We can't afford to go to the Moon!" critics complain. I talk to many different people about space exploration, and I always like to ask them how much they *think* we are spending on the space program, both in total dollars and as a fraction of the federal budget. I find that almost everyone grossly overestimates the amount of spending on the space program. I often hear numbers like 50 percent of the federal budget or hundreds of billions of dollars per year. In fact the budget for NASA (the "civilian" space program) is about $14 billion per year and constitutes less than 1 percent of the federal budget (Fig. 11.3). Expressed as a fraction of the Gross Domestic Product (GDP, the total value of goods and services produced in the country, a measure of our national "wealth"), the NASA budget is much less than one-quarter of one percent (< 0.25%) of the GDP. We could double this amount of spending and not go bankrupt. But throwing money at a problem never solved anything, and doubling the NASA budget would not produce a better or more exciting space program, unless some other changes occur.

The intellectual failure of nerve is not limited to people outside the space program. Setting a long-term goal to provide a "mission" for our space program would do a lot to get us back on track. The current NASA strategic plan (neither "strategic" nor a "plan") lists the five "businesses" of the agency: aeronautics, technology, science, "Mission to Planet Earth," and human spaceflight. Yet listing agency activities does not make a "mission." Arguably, some of these activities could be done more appropriately by other entities. In fact, keeping the agency infrastructure funded and running, regardless of what it is actually *doing*, has become the principal mission of NASA. All of this is intellectual risk-aversion: We don't want (or dare) to say what we really are. (Hint: NASA's "business" should be to explore the universe with people and machines.)

The third aspect of the failure of nerve is a moral failure. Some people contend that, with all of the problems we face on Earth, we should not explore space. They would have all of the

 by Paul [redacted] Spudis

"tremendous resources" that we "pour" into space spent on various social projects. These beliefs assume that space exploration is of intrinsically less societal value than other government activities, and thus this idea constitutes a moral argument. For the people who make such an argument, space exploration is a frivolous activity and spaceflight is something that we should not be doing even if it cost nothing.

It is always difficult to "justify" exploration on cost-benefit grounds, but let me try. We invest in exploration (and basic research, for that matter) primarily for one simple reason: We are not smart enough to know ahead of time all of our needs and wants. Knowledge always pays off, sometime and somehow. Exploration gives us new knowledge, but more important, it *broadens our imagination* so that we can see solutions to problems that we would not have imagined otherwise. Often some of our toughest problems are created because we are not posing the right question. The greater our imagination, the more likely we are to at least recognize the proper question or to pose a question that we can answer or a problem that we can solve. Because space exploration is a challenging endeavor that calls on the best qualities that people have to offer, such as ingenuity and perseverance, we will always be forced to confront and conquer the unknown. Exploration is a very human thing to do!

What's the Solution?

None of the problems outlined in this chapter have easy, simple, or single solutions. Some difficulties are cultural and thus are part of a larger set of attitudes within society as a whole. Others are more easily addressed, and solving them could go a long way toward getting us back on track. Is there a way to reenergize our space effort and give it some direction? What is the path back to the Moon?

Although predicting political landscapes is fraught with pitfalls, I would suggest that a national, government-run effort to return to the Moon, an undertaking similar in pattern to the Apollo program, is unlikely to occur. Apollo came about because of a unique set of political and technical circumstances: We were the right nation in the right place at the right time, with the right

What practical good is space exploration?

"If NASA's budget of $19 billion per year is what it costs to get America's kids to do their maths homework, it's money well spent!" – Fran Bagenal

"Space exploration is the carrot that incites people to become scientifically literate. So I view it as an economic development plan…The economic return is the scientists and technologists who invent the new tomorrow." – Neil deGrasse Tyson

Direct benefits:

• Communications satellites make long-distance phone calls, TV, and the Internet possible.

• Weather satellites save lives, when the warnings are heeded.

• GPS and other navigation satellites also save lives, and speed commerce.

• "Spy" satellites prevented World War III. They made it impossible for the Soviet Union to invade Western Europe by surprise.

• The pictures of Earth taken by the Apollo astronauts directly inspired the founding of modern environmentalism.

Indirect benefits:

• Science began as an investigation of planetary motion, by Copernicus, Galileo, Kepler, and Newton. Without modern science, you'd probably never have heard of indoor plumbing, soap, antibiotics, or cell phones. It's likely you wouldn't be alive at all: smallpox, plague, cholera, and death during childbirth would be common. Superstition and witch hunts would also be common. You'd likely survive by subsistence farming as a serf, or as a slave. You probably wouldn't be a noble, since there weren't many of them.

• Astronomers kept records of sunspots for centuries before their nature was understood. We now have plenty of technology affected by solar activity, including radio, cell phones, and GPS. What was once an obscure curiosity is now practical business, because we can't always know all our wants or needs in advance.

• The greenhouse effect in the atmosphere of Venus alerted us to the hazard of allowing it to become a problem in the atmosphere of Earth. The real value of studying the planets is how they help us understand that most important planet, Earth.

• Mars was similar to Earth during its first billion years. Why is there no obvious life on Mars now? Knowing this might be useful, for making sure that life survives on Earth.

• Fewer people world-wide are employed at learning about impacts by asteroids and comets than work at an average fast-food restaurant. As Larry Niven observed, "The dinosaurs became extinct because they didn't have a space program."

• The computer aboard the Apollo Lunar Module was the direct ancestor of the original personal computer. Its design was pushed by the need to be small and lightweight, unlike most computers of its day. Solar panels and fuel cells were developed for use in space flight. Teflon was invented for it. Velcro was popularized by it. Space flight creates economic opportunities because of the inventor's paradox: the more ambitious goal can have a better chance of success, because more possibilities are open. Wars also do this, but space flight is so much more fun.

• Politics does matter. The last time humans walked on the Moon, they were Americans racing Russians. Next time, they may be Americans racing Chinese—or they may be Chinese.

• Understanding our place in the Universe is important for the human spirit. So is fostering a spirit of adventure. This is why children are so often interested. Among the sciences, astronomy and space exploration have educational value rivaled only by paleontology.

"We need art as we need dreams," [astronaut] Wally Schirra concluded.

"Dreams? Did you say dreams?"

"Without our dreams we wouldn't be where we are: dreaming of going to other planets, to other solar systems, and finding other Earths, our Earth, among billions of stars."

"Our Earth? Did you say our Earth?"

"Certainly. Because it's our Earth, it'll always be our Earth that we're looking for, it'll always be our Earth that we discover. I don't dream about the Moon. I know enough about the Moon to know how unpleasant and inhospitable it is. There's not one bit of Moon that's worth the Earth or what we could bring back to Earth as a trace of civilization. I don't dream about Mars…Mars and the Moon are two ugly islands. So then, you say, what's the point of going to them? The point is to be able to say I've been there, I've set foot on them and I can go further, to look for beautiful islands…"

– From *If the Sun Dies*, by Oriana Fallaci