MISSION TO THE UNIVERSE *

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Abstract. This paper represents a commentary on the importance of communicating science to the general public, and offers specific suggestions on how best to gain public support for space astronomy. The presentation of space astronomy makes use of the contextual framework called Mission to the Universe, as developed by an international working group of astrophysicists and by the author.

> "Humanity has embarked on a great voyage of discovery, with a mission to understand the origin, nature, and fate of our universe. Our ships are an international fleet of space observatories. Our captains are scientists from nearly every country of the world. All of us can be the explorers. Come share in our adventure..."*

More than 35 years after humans first launched satellites into space, space astronomy is at a crossroads. On the one hand, the health of the field has never looked better. An unprecedented number of space astronomy missions are already underway or scheduled to be launched in the near future, and new discoveries are being made at an incredible rate. On the other hand, budgetary cutbacks are threatening plans for future missions and it is becoming increasingly difficult to generate public and political support for space astronomy research. Obviously, the uncertain future of space astronomy is tied up with a myriad of other political issues including weak economies, large governmental budget deficits (in the US, at least), and many pressing social problems. Nevertheless, I believe that space astronomy is both sufficiently interesting and sufficiently important — to the short and long-term health of our civilization — to generate strong public and political support. In this paper I outline my personal beliefs concerning the importance of space astronomy, and explain why I believe it ought to be supported by the global public. It is my hope that these ideas will prove useful to other astronomers in articulating the benefits of our field.

If we hope to show the public why space astronomy is important, we must begin by considering how the public views science in general. I believe that most non-scientists hold great misconceptions about the nature of science. Instead of being recognized as a process for learning about the universe, most people think of science as a collection of facts. Because "facts" are sometimes in dispute, this leads some people to think that all of science is in dispute.

Thus, for example, some people will as readily dismiss a well-established theory like the theory of evolution as they will dismiss the latest estimate of the Hubble constant. Unless we can teach the public to appreciate the scientific process, we

* Presented at the 2nd UN/ESA Workshop, held in Bogotá, Colombia, 9–13 November, 1992.
* From the cover of NASA's Mission to the Universe brochure (NASA 1993), written by the author.

Astrophysics and Space Science **214:** 225–235, 1994.

cannot expect them to differentiate between isolated measurements and the great bodies of evidence that support well-established theories.

Another misconception about science holds that scientific research is cold and dull, involving the "cookbook"-like application of a rigid set of rules known as the "scientific method." If we want the public to take an interest in science, we must show them the creative and emotional aspects of research. Many of the most important discoveries in the history of science — such as Einstein's theory of relativity, Darwin's theory of evolution, Maxwell's discovery that light is an electromagnetic wave — arose from intuitive "leaps" that required as much creativity as the creation of a work of art or music. As with a work of art or music, an appreciation of the creative genius that lies behind a scientific discovery can evoke a strong emotional response. Our own passion for science derives in part from the emotions that we, as scientists, experience when we gain new insights into the beauty of nature. Only if we can communicate this passion to the public will they learn to understand science as a human endeavor.

A third misconception about science — one that is unfortunately held even by some scientists — is that it belongs to scientists alone. This belief leads to the stereotype of scientists as "men in white coats," who coldly and calculatingly seek to acquire power over nature. Because the stereotype generally depicts scientists as men — and usually Caucasian — women and people of non-white cultures are discouraged from taking an interest in science. That it sees scientists acquiring "power" over nature feeds the myth that scientists are sinister or mad. To combat this stereotype we must show that science belongs everyone. When Newton discovered the Law of Universal Gravitation the entire human race advanced, not just Isaac Newton. We, as scientists, must see our role as revealing nature, not as owning it.

Indeed, I believe we should view ourselves as the fortunate few who have been given the opportunity to explore the universe on behalf of the human race. When we learn to share our creativity, our passion, our excitement, and our discoveries with everyone, then everyone will love science.

A fourth misconception is that many people imagine science is somehow independent of the social fabric. They fail to appreciate how science is intertwined with social, economic, and political issues, and thereby consider scientific literacy to be of little importance to their lives. Scientists, too, often neglect the social connection by thinking of science as unbiased and objective. In fact, as clearly shown by Thomas Kuhn's ideas about scientific paradigms, science very much reflects the times and the society in which it takes place. As an extreme example, witness how readily many scientists in the past took part in experiments on human subjects that would now be considered immoral. As scientists, we must stress the power and value of the scientific method. At the same time, however, we must not pretend that our ideas are formed independent of social, political, and economic forces. We must show how science really works. We must teach how science both shapes, and is shaped by, the social fabric. Then, and only then, will the public fully realize the relevance of scientific literacy to their lives.

Perhaps the most insidious misconception about science is that it is *too hard* to be appreciated by the average person. This is insidious because it feeds all of the other misconceptions, and prevents many people from even trying to comprehend science. Yet it is a very strange idea. Why is it that so many people believe that you have to be as smart as Einstein to understand and appreciate the Theory of Relativity? Most people will acknowledge that they are not the musician that Mozart was, yet his music is universally loved. We must teach the public that same idea applies to science. While it may be true that it requires a rare talent or genius to make scientific discoveries, an appreciation of those discoveries should be as accessible to the average person as an appreciation of the music of Mozart.

With these general observations about science in mind, I now turn to the particular issue of generating support for space astronomy. The challenge actually is made more difficult by the large number of missions that are in operation (Box 1). We cannot possibly expect the public to understand each mission individually — I suspect that most of the readers of this paper are not familiar with all of the listed missions. Instead, we must develop a contextual framework for explaining space astronomy research. At the Second Pacific International Space Year Conference, held in Hawaii in October 1991, an international working group* of astronomers proposed the concept of *Mission to the Universe*. Quoting from the working group report (WGAISY, 1991):

> "The scientific theme of *Mission to the Universe* is to investigate the origins of planets, stars, galaxies, and the universe itself, and to make discoveries about diverse types of objects using the broad range of wavelengths possible with space telescopes."

Mission to the Universe represents a framework with both scientific and public value. For the international scientific community, it points out that there is a great need for coordinating the science of the many space astronomy missions. Indeed, the working group recommended several specific initiatives including: improved coordination of future instruments and missions; expanded opportunities for scientific fellowships and international exchange; and facilitating multi-mission analysis through data sharing and electronic networks, and by coordinating the international archives of space astronomy data. The latter initiative has an especially global flavor, encouraging nations with existing computer networks and archives to freely share their data with the rest of the world, while helping other countries to establish compatible networks. For the public, the concept of *Mission to the Universe* offers a context for the multitude of missions. The word "mission" is meant to evoke the sense of a great quest, like the ancient voyages of discovery, that belongs to the entire human race. (The name was also chosen to show the parallels with the more widely known "Mission to Planet Earth" and "Mission from Planet Earth" initiatives.) In addition, it is meant to show that a multitude of individual space

* Co-chaired by Charles Beichman (USA), Fumiyoshi Makino (Japan), and Jean-Pierre Swings (Belgium). The author was a member of the working group.

BOX 1: THE INTERNATIONAL FLEET OF MISSION TO THE UNIVERSE

During the 1990s, more than 20 spacecraft — an international fleet for *Mission to the Universe* — will probe the skies across the entire electromagnetic spectrum. Listed below are the space observatories expected to be collecting data during 1992 or 1993. The lead countries and the year of launch are in parentheses, followed by a brief description of the astronomical objectives.

ALEXIS — Array of Low-Energy X-ray Imaging Sensors (U.S., 1993): Study of the diffuse X-ray background and soft (low-energy) X-ray sources.

Astro-D (Japan/U.S., 1993): X-ray spectroscopy of cosmic sources.

CGRO — Compton Gamma Ray Observatory (U.S., 1991): The largest and most sophisticated gamma ray observatory; centerpiece of the Interplanetary Gamma Ray Burst Patrol (IGRBP).

COBE — Cosmic Background Explorer (U.S., 1989): Study of the remnant radiation from the Big Bang; also infrared imaging.

DXS — Diffuse X-ray Spectrometer (U.S., 1993): Study of X-ray emission from interstellar material. Carried on a 1-week Shuttle flight.

EUVE — Extreme Ultraviolet Explorer (U.S., 1992): The first all-sky survey in the extreme ultraviolet.

Galileo (U.S./Germany, 1989): Planetary probe bound for Jupiter; also can be used for astrometry.

Gamma-1 (Russia (launched by the former Soviet Union), 1990): Gamma-ray observations; part of the IGRBP.

GRANAT (Russia (launched by the former Soviet Union)/France; 1989): Hard (high-energy) X-ray and gamma- ray observations.

Hipparcos (ESA (European Space Agency), 1989): Used in measuring stellar distances.

HST — Hubble Space Telescope (U.S./ESA (European Space Agency), 1990): The largest telescope ever placed in Earth orbit for visible and ultraviolet astronomy.

IUE — International Ultraviolet Explorer (U.S./ESA (European Space Agency)/U.K., 1978): Ultraviolet spectroscopy of stars, galaxies, and intervening material.

KONUS/WIND (Russia/U.S., 1993): Gamma-ray observations; part of the IGRBP.

Mars Observer (U.S., 1992): Primarily a Martian orbiter; also part of the IGRBP.

Mir/KVANT (Russia (launched by the former Soviet Union), 1986): An assortment of astronomical instruments on the Mir space station.

ORFEUS (Germany/U.S., 1993): Far and extreme (high-energy) ultraviolet spectroscopy of stars and the interstellar medium.

Pioneer 10, 11 (U.S., 1972, 1973): Visited Jupiter and Saturn in the 1970's; now continuing outward in search of the boundary between the solar wind and the interstellar medium.

PVO — Pioneer Venus Orbiter (U.S., 1978): Primarily a Venus probe; also part of the IGRBP. (Ceased operations in 1992.)

ROSAT — Roentgen Satellite (Germany, U.K., U.S.; 1990): All-sky X-ray survey and detailed studies of X-ray sources.

Ulysses (ESA (European Space Agency)/U.S., 1990): Flying over the pole of the Sun; also part of the IGRBP.

Voyager 1, 2 (U.S., 1977): Visited the giant planets in the 1970s and 1980s; still used for ultraviolet astronomical observations.

Yohkoh (Japan/U.S. 1991): Studying the nearest star, our Sun, in X-rays.

observatories, studying the universe across the entire electromagnetic spectrum, is necessary in order to obtain a true picture of the universe.

The essence of *Mission to the Universe* as a contextual framework for explaining space astronomy lies with the fact that most people are intrinsically interested in learning about the universe. People of every culture in every epoch of history have sought to understand their place in the universe, as well as their origins and evolution. With such global interest it is not difficult to convince people that *Mission to the Universe* is intellectually worthwhile. (Selected text that makes this case is printed in Box 2, taken from NASA's *Mission to the Universe* brochure.) The more difficult task is to justify the cost of the space observatories that are necessary to the mission.

After all, lots of things are interesting, but the world today faces many deep problems. Millions of people go to bed hungry each night, and over a billion live in conditions of extreme poverty. Even wealthy nations, like the United States, face deep economic uncertainty. Pollution and environmental destruction are threatening the very fabric upon which our ultimate survival depends. Isn't the study of the universe a luxury? Wouldn't it be better to devote our time, energy, and money to the more immediate problems confronting our civilization?

Tough questions, but I believe that the answer to each of them is "no". Indeed, I believe that the study of the universe is critical to the future well-being of our species. Thus, I will conclude this paper by offering six important reasons why I believe the world should support *Mission to the Universe* now.

First, the study of the universe offers us *new perspectives*. For most of human history, we assumed that the Earth — and, by implication, humanity — was at the center of the universe. It is only about 400 years ago, with the work of Copernicus, Kepler, and Galileo, that we finally proved otherwise. Yet the implications of this discovery still, in my opinion, have not been widely grasped. My favorite illustration of this point comes from a quote by the Dutch scientist Christian Huygens, in the late 1600's. Among his many contributions to science, Huygens was the first to identify the rings of Saturn, using a telescope he designed and built, and the first to make a reasonable estimate of the distances to the stars. He may have been the first person in history to truly understand that the planets and the stars constitute real worlds, in many cases far larger than the Earth. And this is what he said:

> "How vast those Orbs must be, and how inconsiderable this Earth, the Theatre upon which all our mighty Designs, all our Navigations, and all our Wars are transacted, is when compared to them. A very fit consideration, and matter of Reflection, for those Kings and Princes who sacrifice the Lives of so many People, only to flatter their Ambition in being Masters of some pitiful corner of this small Spot."
> Christiaan Huygens, c. 1690*

He had discovered a new perspective on the Earth, and he almost immediately recognized the impact this should have on human behavior. Yet few people under-

* I took this quote as written in Sagan, 1980.

BOX 2: SELECTED TEXT ON MISSION TO THE UNIVERSE

The following selections are taken from NASA's Mission to the Universe fold-out brochure (NASA, 1993). They are included to indicate how the concept can be presented to the public. Limited numbers of this brochure are still available. To request a copy, write to the author at: Center for Astrophysics and Space Astronomy, Campus Box 389, University of Colorado, Boulder, CO 80309.

Mission to the Universe
Mission to the Universe is a scientific effort created by astronomers from around the world during the 1992 International Space Year. Using existing and planned space observatories, along with telescopic observations from the ground, Mission to the Universe will be a decade-long campaign to explore the universe and to spread humanity's new view of the cosmos to the global public.

Mapping the Universe
Like the ancient cartographers who compiled data returned from voyages of exploration, astronomers have compiled observations with telescopes for centuries. The cartographers eventually succeeded in making maps, crude at first, of the entire surface of the Earth. Today, we are on the verge of a similar breakthrough in astronomy. During the next decade, we expect to complete the first comprehensive maps showing the structure of the entire universe in every wavelength of light.

Voyage of the Mind
Like the great voyages of exploration in centuries past, Mission to the Universe is a voyage of discovery, opening our eyes to new worlds and new ideas. Unlike these past expeditions, however, ours is primarily a voyage of the mind. Our observatories are like sensory extensions, allowing us to "see" types of light that are invisible to human eyes. Without leaving our home on the Earth, we can now observe the faint, ancient light of distant objects. Then, using the power of our intellects, we can analyze our data to gain a new understanding of our universe and ultimately of ourselves.

The Universe from Space
The advent of observatories in space has revolutionized our ability to explore the universe. The light our eyes can see, which we call "visible light," is only a very tiny part of the complete electromagnetic spectrum. Every part of this spectrum can reveal new insights into the cosmos, but Earth's atmosphere prevents all except the visible light and portions of the radio and infrared from reaching the ground. Thus, only by placing observatories in space can we obtain a complete picture of the universe. In addition, even visible light observations are enhanced from space, since the natural turbulence of our atmosphere tends to blur images of distant objects.

Mission for Everyone
Through the science of astronomy we seek to answer grand questions about ourselves and our place in the universe. We strive to learn how the universe began, how it evolved to its present state, and how it will change in the future. In the process, we also learn about our origins and the origin of our planet. Mission to the Universe is truly a mission to understand ourselves.

BOX 2 *Continued.*

Mission to the Universe is also a mission of hope for the future. Its international character, involving people of many races and cultures, provides a model of global cooperation that may help us learn to live together in peace. Its scientific results will help us to develop a greater appreciation for the beauty and fragility of the Earth, encouraging the global effort to preserve our environment. As we confront the challenges facing our civilization, Mission to the Universe beckons with a promise for tomorrow, a promise of infinite new worlds and new ideas to explore.

Be an Explorer

Be an explorer. Gaze upward at the stars. Learn all you can about astronomy, and stay informed as astronomers probe the secrets of our universe. Books, newspapers, magazines, and television regularly carry information about the latest discoveries. Visit a planetarium or an observatory. A great adventure is under way, and it requires only your interest to be a part of it.

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stand this perspective today, three hundred years later. A survey conducted in the United States a few years ago found that some 20% of adult Americans were unable to say whether the Earth goes around the Sun, or vice versa. If we extrapolate to the rest of the world, taking into account that the average global education level remains well below that in the industrialized countries, I think it is conceivable that a majority of the humans living today are unaware that the Earth is not the center of the universe.

I believe it is exceedingly important that we communicate this knowledge to everyone, and that we continue to explore the universe to gain further new perspectives on ourselves. As Huygens suggested, I believe that if everyone understood this perspective, we would find people much more willing to live and work together, and we would find wars, hatred, and destruction far less common.

I also note that all of the space sciences, not only astronomy, contribute new perspectives to humanity. By presenting scientific discoveries in the context of perspectives, we can draw a connection between science and the everyday concerns of the citizens of the world. (As examples of these perspectives, see the eight perspectives offered in Box 3 from NASA's "Perspectives From Space"* poster set.)

The second reason for studying the universe now is *education*. Children are intrinsically fascinated by the stars, and all humans look to the skies in a quest to understand our nature and existence. Astronomy is therefore ideal for capturing the imagination of young children, and its interdisciplinary nature makes it possible to use astronomy to generate enthusiasm for a wide variety of other subject areas including art, history, social sciences, mathematics, drama, literature, and writing. Further, astronomy has long, deep roots in every human culture and among women

* Further information about the "Perspectives From Space" poster set (NASA, 1992) is given in the companion paper by Bennett and Morrow, also in this issue. Text from the poster set was written by the author in collaboration with more than twenty other individuals from NASA Headquarters.

BOX 3:
PERSPECTIVES FROM SPACE

The "Perspectives From Space" poster set (NASA, 1992) illustrates eight distinct perspectives on eight distinct posters. The text introducing each perspective, printed on the backsides of the posters, is reproduced here.

1: Perspectives From Space — Earth, an Integrated System.
Images of the Earth from space, and satellite studies of the global system and global change, have brought us a dramatically new perspective on the relationship between our species and our planet. When we see the Earth as a beautiful, blue oasis set against the foreboding blackness of space, we immediately recognize its unity and its fragility. Our continuing studies help us to better understand how human activities may be affecting the health of the environment on which we depend for survival. With our new perspective, hopefully, we can learn to preserve the astonishing splendor of our home planet.

2: Perspectives From Space — Patterns Among Planets.
Once, we knew only one world, Earth. Now, through telescopic images and robotic space probes, we know intimate details about the nine planets in our solar system, as well as of numerous moons, asteroids, and comets. From this perspective, we have found that many features of our Earth are shared by other worlds, and we can better appreciate the unique features of our planet that make possible its great diversity of life.

3: Perspectives From Space — Our Place in the Cosmos.
Just a few hundred years ago people believed that the whole universe revolved around the Earth. Today, we recognize that we are small compared with the vast expanses of space and time. Yet we can touch the cosmos through our intellect. Aided by Earth and space-based observatories, our minds have probed the very beginnings of the universe. We have seen, and are coming to understand, many of the laws by which the entire universe operates. Awe-inspired by our new perspective on the grandeur of the cosmos we gain a greater appreciation of, and respect for, the unique treasures of the Earth, life, and our own species.

4: Perspectives From Space — Our Sun, The Nearest Star.
The Sun affects every aspect of the environment on Earth and is the ultimate source of sustenance for life. Yet we now know that it is only a rather ordinary one among a myriad of stars in the universe. Over time scales of millions or billions of years stars are born in vast clouds of gas, live producing energy by nuclear fusion, and die in violent outbursts. At death, they release the chemical materials forged in their nuclear furnaces — the materials of which we, and the Earth, are made. In our new perspective, we are intimately linked to the Sun and the stars.

5: Perspectives From Space — Oasis of Life.
Life on Earth is remarkable not only in its existence, but in its great diversity. Nowhere else, yet, have we found evidence of life. But the precursors of life — organic molecules — are abundant in our solar system, and we have found evidence that some worlds, like Mars, may once have had conditions suitable for life. We wonder if life might have arisen among some of the billions of other stars in our Galaxy and, with great radio telescopes searching the skies, we listen hopefully for

BOX 3 *Continued.*

a signal from extraterrestrial intelligence. As we strive to understand why the Earth teems with life, and ponder the possibilities of life elsewhere, we develop new perspectives on the origin, value, and beauty of life on Earth.

6: Perspectives From Space — The Influence of Gravity.
Gravity — we rarely think about it, yet many of the physical processes we take for granted on Earth are dependent on it. Because of gravity a dropped rock falls to the ground and water flows downhill. Gravity causes ice to float on water, because the ice is less dense. Weather is driven by gravity as lighter, warmer air rises and cool, dense air falls. Without gravity we wouldn't even have air to breathe, because gravity's pull is what keeps our atmosphere from drifting away. In space, however, a condition of continuous free-fall effectively eliminates the effects of gravity. Only then can we fully appreciate the influence that gravity has on our lives.

7: Perspectives From Space — The Spirit of Exploration.
For centuries, men and women have explored the Earth from the depths of its oceans to the high peaks of its mountains. Today, we are reaching beyond the confines of our home planet into the vast frontier of space. Already, humans have walked on the Moon, and robotic spacecraft have landed on Venus and Mars. As we contemplate the prospects for grand, international endeavors, such as returning to the Moon or sending humans to Mars, we gain a new perspective on the long-term future of our species. Human exploration of space represents our hopes for a future in which our civilization rises to the challenges facing its survival, reaps the rewards of save, technological advancements, and sows a peaceful, prosperous heritage that literally will take our descendants to the stars.

8: Perspectives From Space — Global Cooperation.
The beginnings of the space age, celebrated during the 1992 International Space Year, come at a crucial time in human history. For the first time humans have the capability to alter the entire planet for better or for worse. The perspectives we gain from space help us to understand the challenges facing our civilization. Our planet, once a seemingly vast and limitless world, now appears small, fragile, and threatened. Space age technologies, in communication, transportation, and weaponry, transcend political and cultural borders. No longer can nations, or peoples, live in isolation. But will we come together in global cooperation, or in global conflict? International efforts in space bring us many new perspectives, but perhaps none is more important than the realization that we are, after all, one humanity, living on one Earth.

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and men alike. Every child can therefore feel ancestral "ownership" of astronomy, making it ideal for motivating scientific study by women and members of cultural groups presently under-represented in science. (For greater detail on the unique educational benefits of astronomy see the companion paper by Bennett and Morrow in this issue.)

The third reason is *global cooperation.* Astronomers have been leaders in advancing international scientific cooperation. Nearly all space astronomy missions are international in nature. Many are designed, built, and operated cooperatively through international partnerships, and space astronomy data are available to astronomers throughout the world. As a case in point, scientists from over 100 countries have worked with space astronomy data collected by NASA. I believe that the example of international and cross-cultural cooperation that has allowed us to achieve so much in space astronomy can be an inspiration to nations seeking a peaceful road to a secure and prosperous future.

Fourth, *Mission to the Universe* is important for *technology*. Space astronomy spurs advancements in optics, detectors, cryogenics, advanced computation, networking, remote sensing, and more. These technologies are likely to be crucial to the future economic prosperity of all citizens of the world. Indeed, many people have argued that these "spin-offs", alone, make our investment in space science pay for itself several times over.

Fifth, space astronomy missions play a vital role in the *training* of young scientists and engineers. In the US, the development of an instrument to be flown in space or on a sub-orbital mission is the formative event in many young careers. Two key features of developing instrumentation for space astronomy are particularly important: the instruments are often limited enough in scope so that a single person can be involved in every aspect of their development; and, at the same time, they require complex teamwork to ensure that they integrate properly into a spacecraft or rocket. Thus, work on space astronomy programs teaches a *systems* approach to science and engineering, helping young researchers to develop a "can-do", mission-oriented spirit.

Finally, the last reason I will give for making our study of the universe a high priority today is that it provides humanity with a *vision for the future*. The nightly news is a constant reminder of the many threats to our survival — poverty, hatred, war, environmental destruction, overpopulation, and so much more. While there is no doubt that we must deal aggressively with all of our problems, I believe that we cannot hope to solve them unless we simultaneously develop a hopeful vision for the future. The human race can be thought of like a single person fighting severe illness, whose will to survive depends on having a vision of future health. While the entire space program focuses on a long-term promise for the future it is astronomy, in a way, that represents the farthest vision of all.

Consider humanity, for a moment, with a million-year perspective. A million years ago our numbers were small, our tools few, and our knowledge very limited. Today, we dominate the Earth, perhaps pressing it too hard toward its limits. Where will be a million years from now?

The only thing we can say for sure is that we will *not* be where we are today. People will not live in the same cities, in the same numbers, with the same knowledge, or the same behaviors. Perhaps we will have succumbed to the problems that afflict us today, and we will be extinct from the Earth. Perhaps our civilization will have risen and fallen through cycles of technology and prosperity, never achieving more than we have achieved at present. Or, perhaps, we will have survived, prospered, and advanced. A person, a nation, or a civilization must do more than just solve the problems of the day. We must always look to the future. In astronomy, we study the stars. Places where we will not go today, tomorrow, in a hundred years, or even a thousand. But a million years is a long time...

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