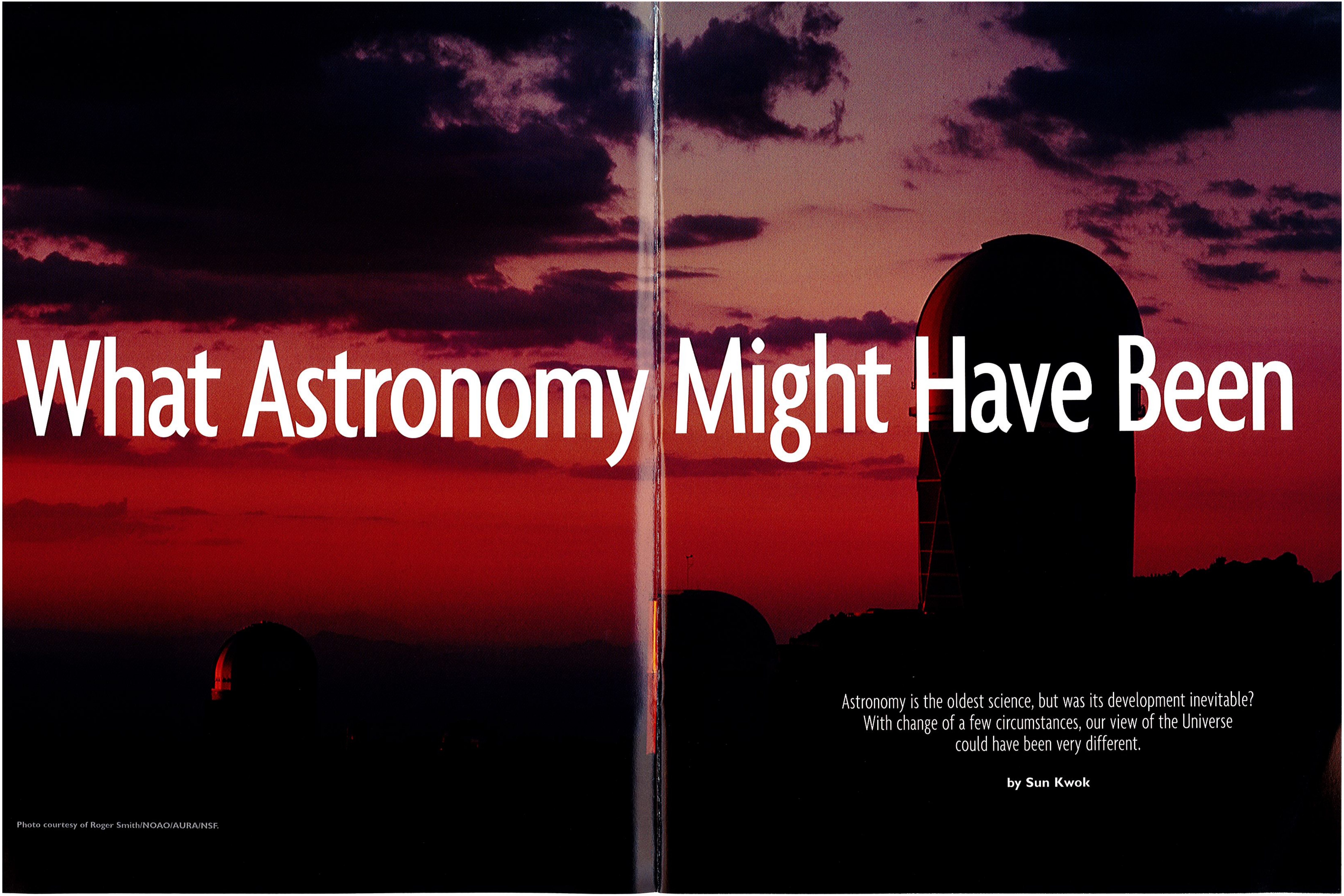
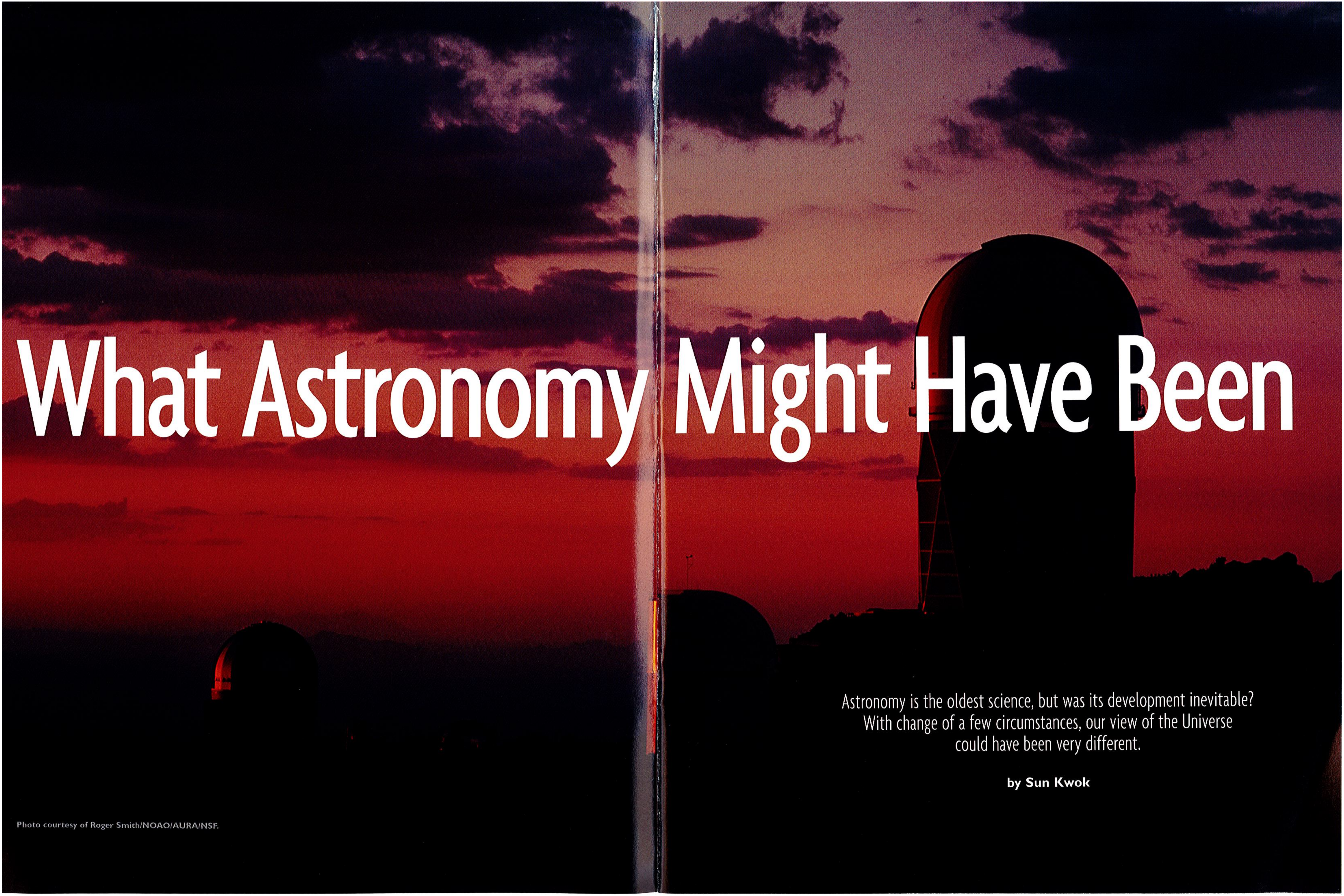


What Astronomy Might Have Been

Astronomy is the oldest science, but was its development inevitable? With change of a few circumstances, our view of the Universe could have been very different.

by Sun Kwok

Photo courtesy of Roger Smith/NOAO/AURA/NSF.



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Almost as soon as humans developed a sense of awareness of their surroundings, they

were awed by the heavens. As the Sun sets, thousands of stars appear in dark skies above us. These glittering stars have varying degrees of brightness and seem to be arranged in patterns. As early humans began to think and imagine the meanings of these patterns, situated in regions of the sky called constellations, they must have wondered a great deal about whether those points of light carried meaning and even messages for them.

Because human activities were highly restricted at night due to difficulties in finding our way around, sky watching was the main activity. The keen observers noticed that the positions of stars are not fixed, and in fact the stellar patterns drift across the sky as the night passes. Further, in subsequent nights, they observed the same stars rising a little earlier each night. As the seasons pass, new stars will rise above the eastern horizon, and old stars disappear below the western horizon. We have stars of summer and stars of winter, and this cycle repeats itself year after year.

The recognition of patterns of nature, and the seeking of explanations for them, is what science is all about. For this reason, we can safely say that astronomy is the oldest science. Another property of science is its predictive power. As the Sun moves across the sky every day, the highest point it reaches gradually changes. In the warm season the Sun reaches high in the sky, whereas in the cold season the Sun seems to drift not much above the horizon. Such seasonal variations of the positions of the Sun allowed early humans to predict the coming of spring, an important capability to those involved in the development of agriculture—farmers need to know when to seed.

The science of astronomy, therefore, had great practical value, and the study of the heavens was a serious business, not just intellectual curiosity. But is the development of the astronomical science in human history inevitable? Could our awareness of the Universe be different under different circumstances? Let us explore these questions.

The Visible Universe

Astronomy is an observational science. Unlike biologists studying plants and animals, astronomers cannot touch the stars. The development of astronomy relied on our ability to observe, and for the first thousands of years, this meant observing with our eyes. As incredible as our vision is compared to our other senses, it is, in fact, quite limited. Our eyes can see only a very small part of the light around us. Although we can differentiate colors of red and blue, we are blind to the infrared and ultraviolet, not to mention radio and x rays.

The development of our visual, or visible, range is not an accident. The range, corresponding to wavelengths between 400 and 700 nanometers, is where the Sun emits most of its light. Since we rely on sunlight to navigate our movements during daytime, it is to our advantage to take maximum advantage of the Sun. Over millions of years, the eyes of our ancestors evolved to respond as much as possible to the available light from the Sun, permitting them (and us) to efficiently capture prey and avoid predators.

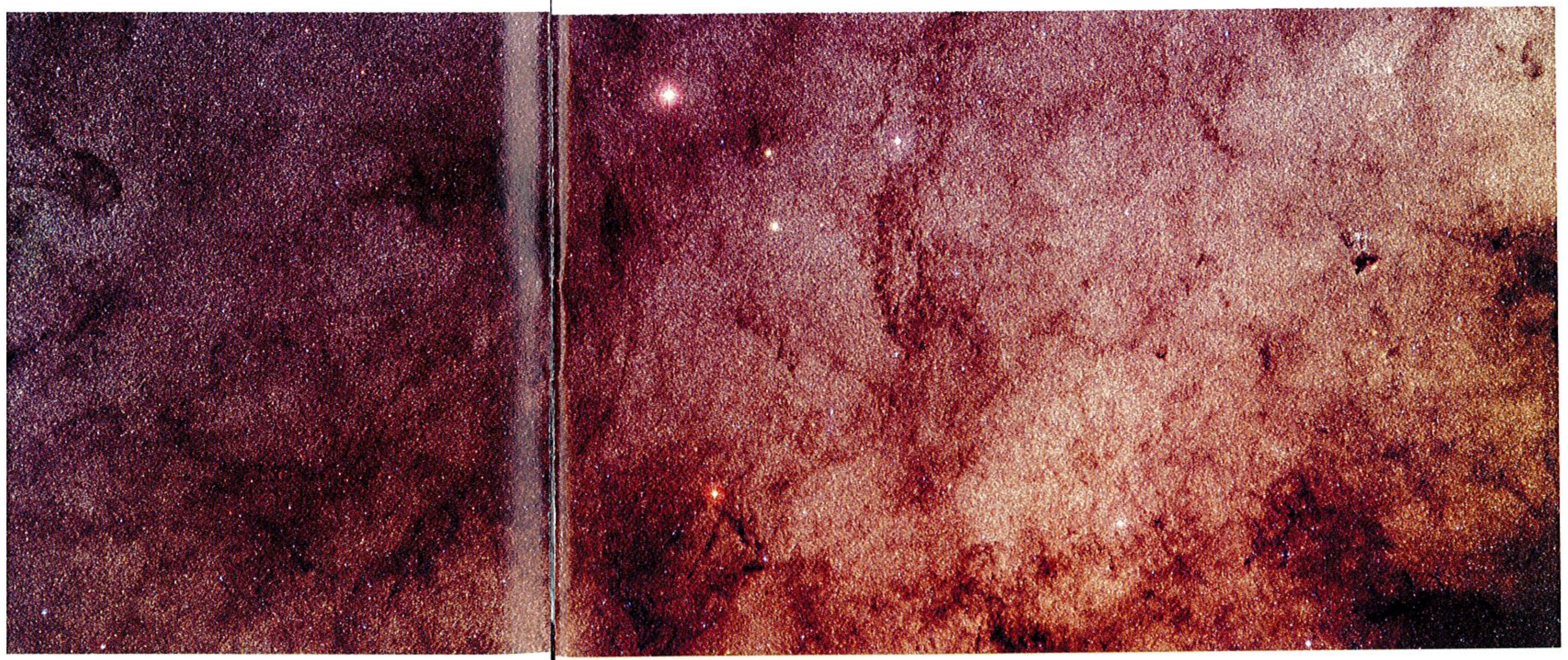
Fortunately, our Sun is a typical star. Although other stars in our Milky Way Galaxy can be hotter or cooler and have different colors, most of them radiate strongly in the visible range. Thus, our visual perception equips us ideally to observe other stars. And because galaxies are collections of stars, our vision is also well suited for the observations of galaxies—e.g., the Magellanic Clouds.

Since the Moon and planets reflect sunlight, they are also bright visual objects. Planets move through the constellations and do not repeat their positions from year to year, and are easily distinguished from stars. The planets Mercury and Venus stay close to the Sun, whereas other planets zigzag in their paths (consider Mars's occasional retrograde motion). Such peculiar behaviors must have puzzled the early sky watchers.

You may be inclined to conclude from all this that the development of astronomy is inevitable on planet Earth. We evolved to possess visual perception, which is ideally suited for observations of stars. Stars move across the sky in daily and yearly cycles, and these apparent motions fuel human curiosity. The movements of the planets are more complicated, but clearly not random. Astronomy has the two essential ingredients for science: patterns and a mystery of origins. These foment in humans strong interest in astronomy.

But are there other elements of our surroundings that could have made the development of astronomy different from its history to this point in time?

Above: Photo ©2003 D. Elfstrom.



Below: The amount of dust toward our galactic center is so high that we can hardly see the other side of the Milky Way Galaxy beyond the Galactic center. The same dust obstruction also prevents us from seeing external galaxies that lie along the plane of the Milky Way. In this photograph of star fields in the direction of Sagittarius (toward the Galactic center), the distribution of dust is apparent and areas seemingly devoid of stars are, in fact, simply obscured by clouds of intervening dust. Photo courtesy of Anglo-Australian Obsevatory/David Malin Images.

Different Days, Different Seasons

The Sun's and stars' daily motions results from Earth's rotation. As our terrestrial location turns to face the Sun, we have sunrise in the east. As our location turns away from the Sun—sunset in the west—the stars begin to appear in the sky and move from east to west. But what if Earth did not rotate? If our planet faced the same direction as it revolves around the Sun, we would have six months of day and a six-month summer; the other six months would be dark and the skies filled with stars. Since we would see the same constellations during those six months, we would be unaware of the other constellations! A person would be familiar with Cygnus and Sagittarius, but totally ignorant of Orion and Gemini (or vice versa). To gain a complete knowledge of the sky, we would have to travel to the other hemisphere just as a person residing in the northern hemisphere has to go to the southern hemisphere to see the southern constellations.

This scenario of a non-rotating Earth is not as ridiculous as it sounds. Uranus's rotation axis lies almost exactly in the plane of its revolution around the Sun, which means it sort of lies on its side in its orbit. A person unfortunate enough to be living near the north or south Uranian poles would experience continuous sunlight for half of a Uranian year (approximately 42 Earth years) with no observations of other stars possible; for the other 42 years, total darkness and non-stop astronomical observations!

Of course, being able to venture around the planet would permit one access to the complete sky, just as the present northern Earth inhabitants traveled south and discovered the southern sky. But no doubt that living on a non-rotating world would have delayed the progress of astronomy.

Two Stars in the Sky

Earth has one parent star, the Sun. Astronomers estimate, however, that over half of all the Galaxy's stars are in binary- or even other multiple-star systems. Had we lived on a planet with two suns, our astronomy would be completely different.

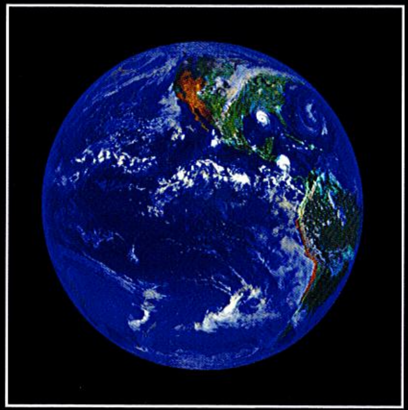
As Earth turns away from one sun, it could be facing the other sun. Our "day" would still be defined by one rotation period of Earth, but the association of day and night with this rotation would be completely lost. The exact timing of light and dark as Earth rotates and revolves around the sibling stars would be determined by the stars' orbits and their respective orientations to Earth. At times there will be two suns in the sky, and other times one during the "day" and the other during the "night."

How would astronomy have developed under these circumstances? Without the regularity of nightly observations, the task would be much more difficult. No doubt with diligence and mathematical analysis, humans would eventually figure out the motion of the two suns and the planets in this alternate solar system. If the two stars were close enough, their gravitational pull would disturb the planets' orbits, but, hopefully, this perturbation would not be not large enough to disrupt completely the emergence of life on Earth (due to extreme seasons, for example). Still, the irregularity of the planetary orbits in such a system would make the Copernican view of the solar system, the Keplerian laws of planetary motion, and the Newtonian theory of gravitation much more difficult to formulate.

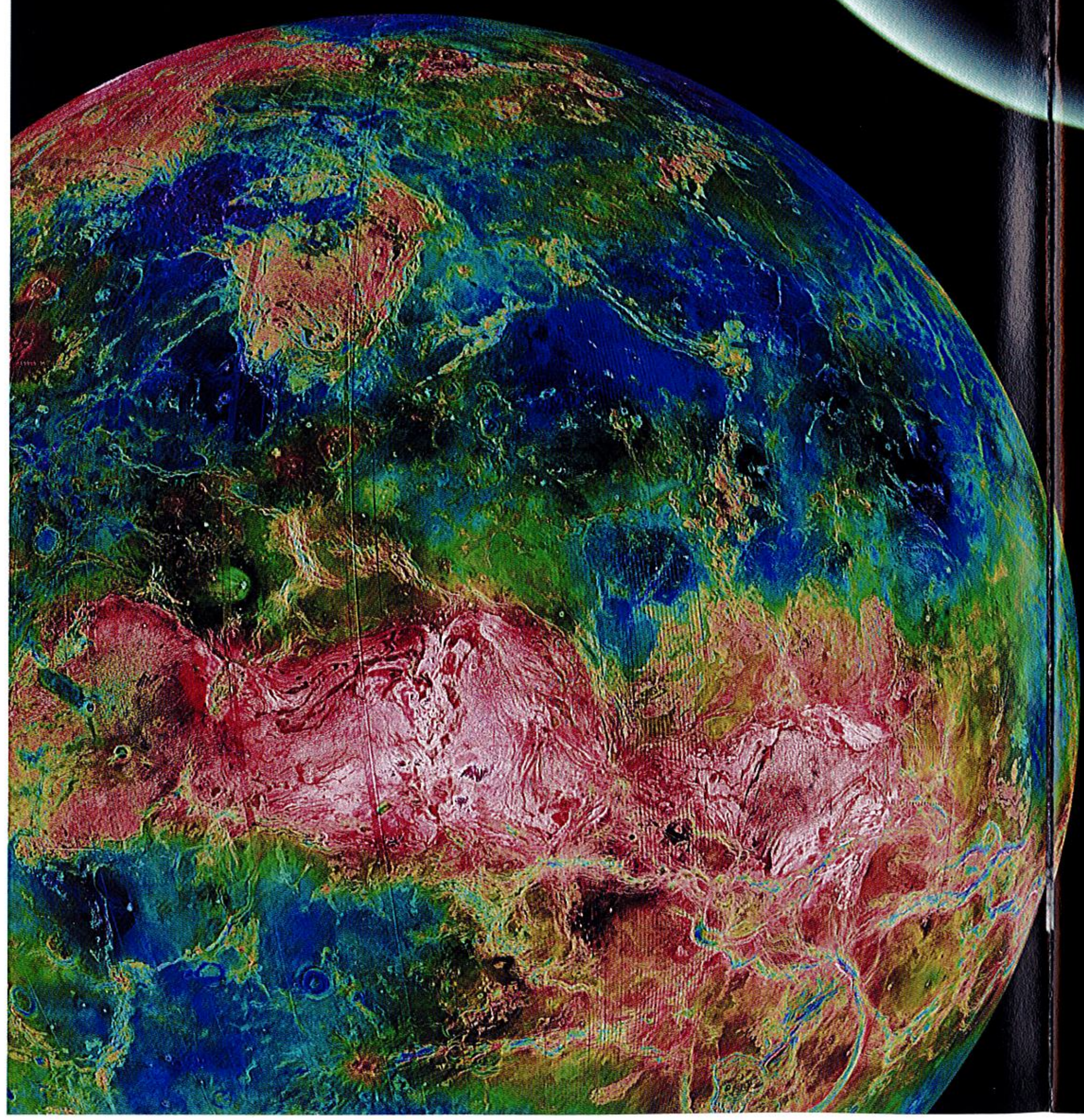
Part of the reason it took so long for us to figure out the planetary motions in our actual Solar System is that planets move in elliptical, rather than circular, orbits. Just imagine how difficult a mathematical problem it would be if the planets moved in erratic orbits in a three-body gravitational system, which has no analytical mathematical solutions—determining, for example, Mars's erratic orbit by observing it from an erratically moving Earth would be tough!

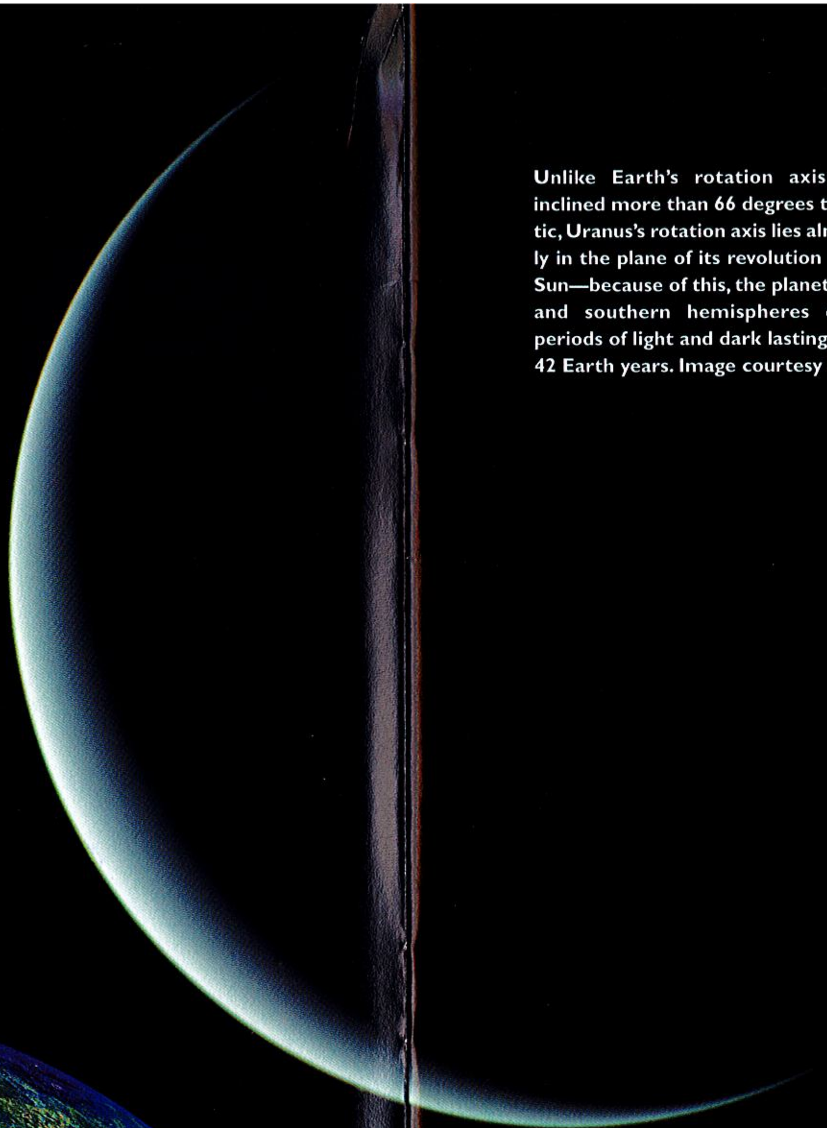
The Obstructive Atmosphere

Thankfully for us and the other air-breathing creatures on it, Earth has an atmosphere. The lower atmosphere contains molecular oxygen, which our bodies use in chemical reactions to generate energy, and

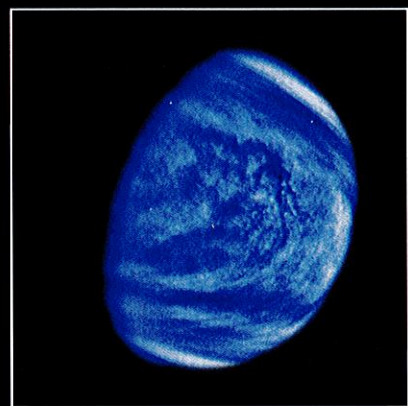


Providing us a stable, fluid environment, Earth's atmosphere—with clouds, water vapor, particulates, etc.—can make astronomical observations difficult if not occasionally impossible. This 1992 image of the Americas and Hurricane Andrew, composed of data from the NOAA GOES-7 satellite, was produced by F. Hasler, M. Jentoft-Nilsen, H. Pierce, K. Palaniappan, and M. Manyin, and is courtesy of the NASA Goddard Lab for Atmospheres and the NOAA.





Unlike Earth's rotation axis, which is inclined more than 66 degrees to the ecliptic, Uranus's rotation axis lies almost exactly in the plane of its revolution around the Sun—because of this, the planet's northern and southern hemispheres experience periods of light and dark lasting more than 42 Earth years. Image courtesy of NASA.



Only a decade of radar investigations of Venus, concluding with NASA's 1990-4 Magellan mission, can reveal high-resolution detail on the Venusian surface—normally invisible to us at visible wavelengths because of the planet's atmosphere (above). Radar map (left) is courtesy of NASA/JPL/MIT/USGS; atmospheric image, NASA/JPL.

the upper atmosphere contains ozone, which blocks harmful ultraviolet rays from the Sun. Water and carbon-dioxide molecules in the atmosphere absorb terrestrial infrared light, warming our planet's surface through the greenhouse effect. With water vapor evaporated from oceans, clouds form in the sky. The same clouds also return water to the ground through rain and snow, providing moisture for plants and drinking water for animals.

However, this same atmosphere so beneficial to life on Earth is also the greatest enemy for astronomy. Clouds block starlight, making the heavens inaccessible to us many days in the year, and currents of air give wobble and wiggle to starlight that reaches the planet's surface. Consider what our ideas about the heavens would be if clouds were a permanent fixture above us by imagining looking skyward from a spot on Venus. Now, this planet, sometimes called Earth's twin, has such a thick atmosphere that were we to stand on its surface (and somehow survive), we could not see any stars overhead. Although the air of Venus is clear near the surface, a thick layer of sulfuric-acid clouds between altitudes of fifty and seventy kilometers reflects away all visible light from the outside. And the reverse is true: Venus's thick atmosphere prevents us creatures outside its atmosphere from seeing down to its surface. Indeed, our understanding of the surface topography of Venus is obtained through long-wavelength, cloud-penetrating, radar imaging.

Could this happen on Earth? Venus and Earth are both terrestrial planets with solid surfaces and are similar in many ways. And though quite different now, even their early atmospheres were the same. A critical difference is that the condensation of water early in Earth's history produced oceans that absorbed much of the greenhouse gases carbon dioxide and sulfur dioxide, and the emergence of living organisms 3.5 billion years ago enriched the atmosphere with oxygen.

Could an intelligent species evolve on a planet with a thick atmosphere? The answer is possibly yes. The greenhouse effect of a thick atmosphere creates a warm environment on the planet's surface, which could be advantageous, in particular for a planet located farther from its star than Earth is from ours. Once civilized and stable, such intelligent life would likely develop sciences such as biology, chemistry, and physics, but not astronomy, at least not until they develop the technology of space flight—imagine their amazement upon emerging from the confines of their planet's atmosphere.

Even Earth's atmosphere is not totally transparent. Water, oxygen, and carbon dioxide molecules in the atmosphere prevent infrared and microwave radiation from reaching the ground. Ozone, while protecting us from the Sun's ultraviolet rays, also prevents us from observing the Universe in ultraviolet, x, and gamma rays. Observations of the Universe in these "colors" were only possible after we acquired the ability to place telescopes in artificial satellites orbiting Earth. This process began in the late 1960s through the launch of a series of space telescopes with capabilities in x-ray, ultraviolet, infrared, and submillimeter wavelengths. By going to space, we have greatly expanded our vision and found a totally new appreciation of the Universe.

Clear Seeing Through the Galaxy

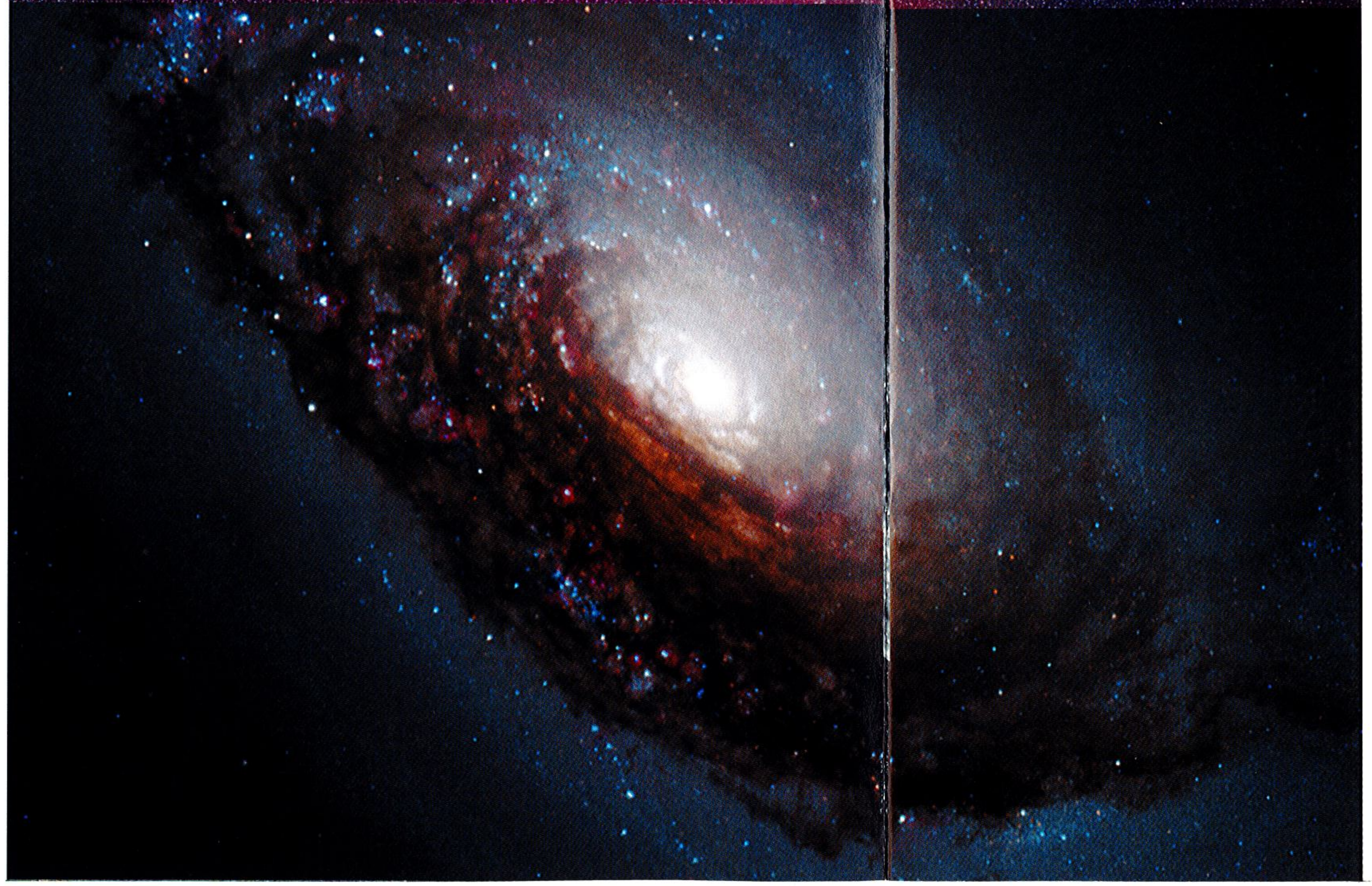
The Milky Way Galaxy contains about 100 billion stars, but they are spread out over an enormous volume approximately 100,000 lightyears across. And the space between stars is not entirely empty either. There are interstellar clouds, some of which are easily observable because they are close to stars—reflection nebulae (e.g., surrounding the Pleiades) reflect light from stars in or near them, and emission nebulae (e.g., the Orion Nebula) shine on their own. Some interstellar clouds are dark; we infer their existence from the absence of stars in a particular direction (e.g., the Coal Sack Nebula).

The most common ingredient of interstellar clouds is atomic hydrogen, which is everywhere in the Galaxy's disk, not just concentrated in interstellar clouds. When the atom is struck by ultraviolet light, its lone electron can absorb the photon and be ejected from the atom. Interstellar clouds, then, obstruct ultraviolet light and stop it from propagating through the Galaxy. Confronting a density of one hydrogen atom per cubic centimeter in the Galaxy's midplane, ultraviolet light with wavelengths shorter than 91.2 nanometers can only travel 0.2 lightyear before being absorbed by a hydrogen atom. Consequently, interstellar space is always cloudy to far ultraviolet light, and we have problems seeing distant ultraviolet stars even if they are observed from a space platform outside our atmosphere.

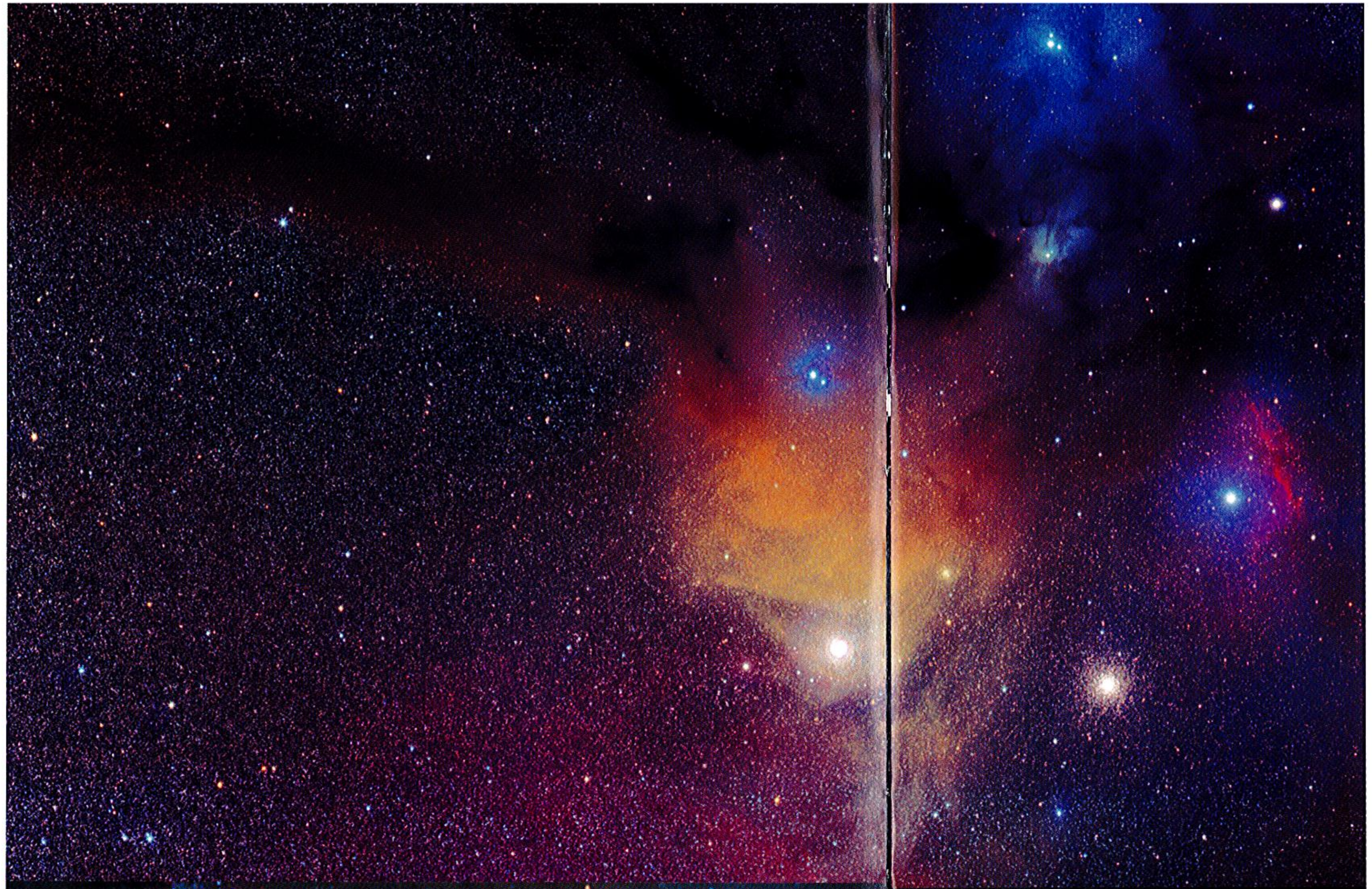
Our actual situation is not as bad as it could be. It turns out that the Sun is located inside a "local bubble," extending over 300 lightyears and containing about 200,000 stars, where the density of interstellar material is lower than is typical elsewhere in the Galaxy. The low density of the bubble allows us to see farther in the ultraviolet than otherwise possible. The origin of this local bubble is not entirely certain, but it was probably created by supernova explosions several hundred thousand years ago. The supernovae swept clean our local environment, leaving behind a "bubble."

The reason far ultraviolet light is selectively absorbed by hydrogen atoms is that interstellar space is so cold and rarified that almost all the atoms are in their ground states. If interstellar space were hotter and denser, some of the electrons would be in higher orbits: in this situation, hydrogen atoms absorb visible light and not just far ultraviolet light. Therefore, excited hydrogen atoms in the local interstellar medium can block the visible light from the Universe, and this would be disastrous for astronomy!

Another source of light obstruction is interstellar dust, made of micron-sized particles, spread throughout our Galaxy and manifest in our observations as dark patches against background fields of stars. These are regions of high concentrations of dust, which obscures our view along these directions. We can see similar distributions of dust in other galaxies, which show up as dark lanes along the galaxies' galactic planes. The total amount of dust toward our Galactic center is so high that we can



This apparently normal, though particularly dusty, spiral galaxy—located seventeen million lightyears away and designated as Messier 64—is believed to be the result of a past merger of a spiral galaxy and one of its former satellite galaxies. Observations in the 1990s uncovered that, while stars in the galaxy revolve in the same direction, large amounts of interstellar gas and dust in the galaxy's outer areas move in the opposite direction, telltale of a past merger. The presence of dust in galaxies is not unusual, and this dramatic image of what some refer to as the "Black Eye" galaxy only demonstrates the ability of small quantities of interstellar material spread over vast distances to obscure light from distant objects. Image courtesy of NASA and the Hubble Heritage Team (AURA/STScI).



The active Rho Ophiuchus region. In this image, which contains Antares, one of the brightest stars in the sky (at right, in center of yellow nebulosity), one can see examples of emission nebulae (red), reflection nebulae (blue), and absorption nebulae (dark). Photo courtesy of and ©2004 by Loke Kun Tan (*www.starryscapes.com*).

hardly see the other side of the Milky Way Galaxy beyond the Galactic center. The same dust obstruction also prevents us from seeing external galaxies that lie along the plane of the Milky Way. In fact, we were not aware of the existence of one of our nearest neighbors, the Sagittarius dwarf galaxy, until 1994 because of dust obstruction in our Galaxy.

What if the Sun were located inside a dust cloud? Again, this is not entirely inconceivable, and there are probably other intelligent beings inhabiting planetary systems inside large, dusty clouds in the Milky Way Galaxy. The view of the cosmos by these aliens would be highly hampered: they would not be aware of many of the optically faint objects such as galaxies, and their view will get better once they develop techniques of radio observations, for radio waves can penetrate dust clouds easily. The first objects they detect external to the Milky Way Galaxy would probably be radio galaxies and quasars, not normal spiral and elliptical galaxies.

Consider, finally, a related situation that is closer to us. As we look up to the Sun, we perceive a round object with clear boundaries. However, unlike the Moon, which has a solid surface, the Sun does not have a real "surface." Our perception of its size and shape is determined by the Sun's apparent size—the size at which the gaseous matter in the Sun becomes opaque. The source of this opaqueness is determined by the same process that I described earlier: the absorption of visible light coming from the Sun's interior by hydrogen atoms in excited states. Because the Sun is much denser and hotter than the interstellar medium, hydrogen atoms are indeed excited and, therefore, capable of absorbing visible light. Our ability of direct, visual observation ends, then, at stars' surfaces. And it turns out a stellar surface is not only opaque in the visible, but also in ultraviolet, infrared, and radio regions of the electromagnetic spectrum. In fact, we can only "see" the interior of stars with a neutrino "telescope."

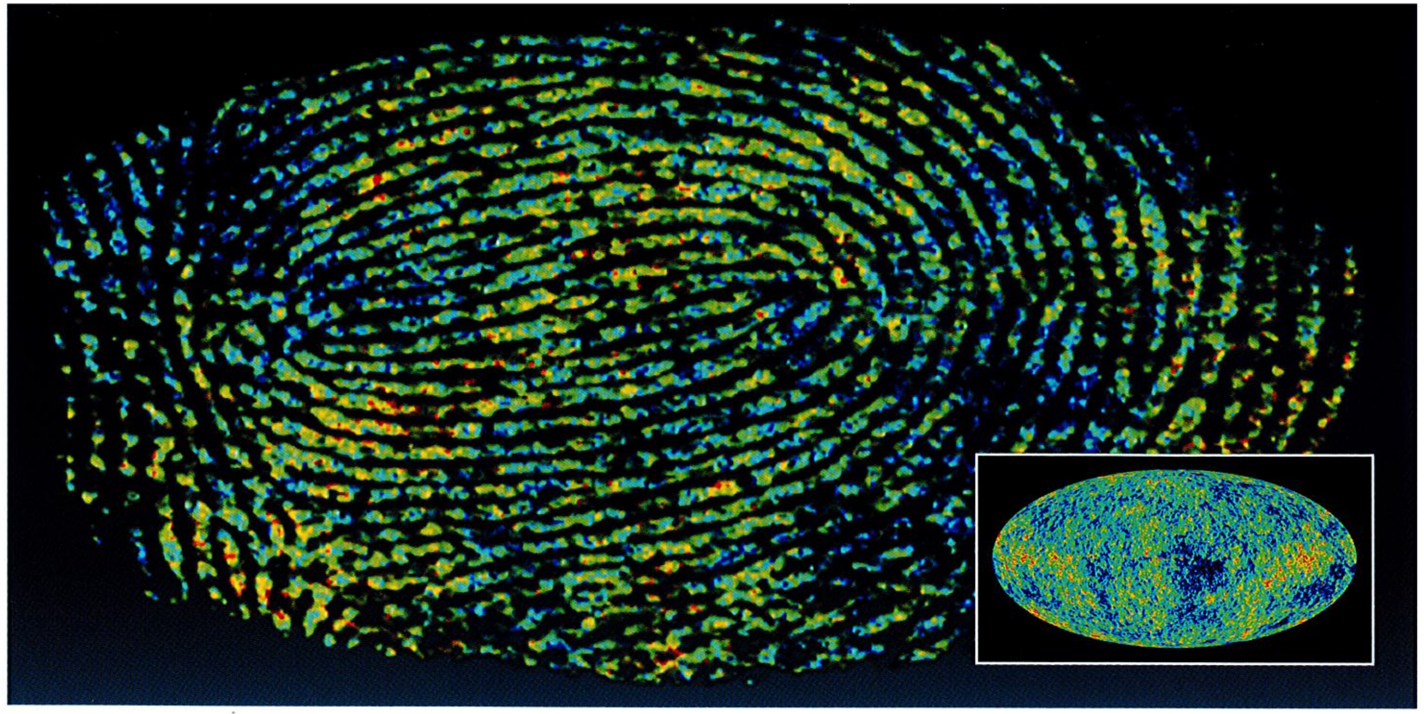
Our ability to observe the stars is, therefore, not just limited by our eyesight and terrestrial and interplanetary environments, but is dependent on the interstellar environment as well. To turn the argument around, the simple fact that we can see stars and galaxies tells us a great deal about the state of interstellar space.

Back at t = 0

If interstellar gas can absorb light, how about intergalactic gas? Indeed, there are intergalactic clouds, and the hydrogen atoms in these clouds also absorb far ultraviolet light. Since the Universe is expanding and light from distant galaxies and quasars is Doppler-shifted to longer wavelengths, these far ultraviolet photons become visible light as they reach us. From the spectra of distant galaxies, we can see that parts of the visible spectrum are removed by intergalactic clouds because of hydrogen absorption.

Hydrogen atoms are not the only absorber of light. Free electrons, if present in sufficient quantities, are also efficient absorbers. In the interior of the Sun where the density is high, scattering of light by free electrons is the prime obstruction of light emerging from the solar interior. In fact, light in the interior of the Sun can travel hardly one centimeter before it is scattered by electrons and has to go through a long zigzag path to reach the solar surface—a trip that can take 30,000 years. In contrast, neutrinos, which are not subject to obstruction by electrons, can fly out from the Sun's core to its surface in two seconds!

Let us consider how free electrons might treat light in an expanding universe. If we extrapolate the current state of the Universe to an earlier time, we discover it must have been hotter and denser. In fact, we will come to a very early time at which all electrons are free and not bound to hydrogen atoms. When the Universe was in such a state, light was totally obstructed by all of those electrons, and the Universe was completely opaque—much as the Sun is opaque today. The Universe only became "transparent" when electrons combined with protons to form neutral hydrogen atoms; astronomers refer to the time of this union as the "epoch of recombination." From the recent Wilkinson Microwave Anisotropy Probe (WMAP) mission, this epoch was accurately deter-



mined to be 380,000 years after the beginning of Big Bang.

This tells us that there is a limit to astronomy. As we look to large distances, we are also looking back in time. However, no matter how large a telescope we construct and where we put it, we will never been able to see the Universe younger than 380,000 years or at distances beyond 13.6 billion lightyears. Not that there was much to see way back then because stars and galaxies did not form until 180 million years after the Big Bang. The only light present before the epoch of recombination was the cosmic background radiation, a universal radiation permeating every nook and cranny.

Data from the Wilkinson Microwave Anisotropy Probe (WMAP) permit us to make the first detailed full-sky map of the oldest light in the Universe. The WMAP image reveals temperature fluctuations (portrayed here as color differences) in the Universe from more than thirteen billion years ago—fluctuations that served as the seeds from which galaxies grew. Much as fingerprints betray a culprit, these fluctuations can betray conditions in the early Universe. Illustration courtesy of NASA/WMAP Science Team.

A Humanless Universe

So far I have discussed the science of astronomy from a strictly human perspective. Yet if the Universe has an objective existence, it can exist and evolve without ever being observed.

A humanless scenario is entirely plausible. The biology of living organisms depends on organic chemistry, which in turn is based on the element carbon. As astronomers applied the knowledge of nuclear physics to astronomy, we learned that the light elements hydrogen, deuterium, helium, and lithium were produced during the Big Bang, whereas all other heavy elements are manufactured in stars. The element carbon is made in old red giant stars through the fusion of helium. However, this nuclear reaction depends on the existence of an excited energy state of carbon, without which the synthesis of carbon would go too slowly: whatever carbon atoms were produced would quickly change into oxygen. The existence of this excited state was predicted by Fred Hoyle in the mid-20th century and experimentally confirmed later by William Fowler. With this coincidence in nature, carbon is created with abundance in stars and serves as the basis for life. With life came human beings and astronomers, and the development of astronomy as a scientific discipline.

Looking Out

With the exception of the study of cosmic rays, neutrinos, and meteorites, the science of astronomy relies on observation of light. For light from an object to reach us, its path has to be relatively clear and without obstacles. But the condition of transparency is dependent on the state of matter and how such matter interacts with light. If matter does not absorb light, it will not emit it. Stars are visible objects because the gamma rays generated in the nuclear reactions deep inside stars are destroyed and converted to visible light by atoms inside the stars. If the outer layers of stars were transparent, there would be nothing for us to observe!

The science of astronomy is, therefore, built on a delicate balance of opacity and transparency. Further, it also depends on our ability to detect light. For many years, we relied on our eyes as the primary source of information. With the development of telescopes and instruments capable of detecting light beyond the visual range, we have gained a greater appreciation of the Universe's diversity. By placing telescopes and instruments on airplanes, balloons, and satellites, we overcome part of the local atmospheric obstructions. Yet obstructions on a larger scale, in and beyond the Galaxy, can never be overcome. Astronomy, as an observational science, must live with these limitations.

We inhabit a unique world. Planets may be common in the Galaxy, but the conditions and surroundings under which they exist are all different. And even though we all inhabit the same Galaxy and Universe, our views and perceptions will be different. Indeed, it would be chauvinistic for us to assume that the science of astronomy will develop the same way everywhere in the cosmos. ■

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