Lecture by Professor Geoffrey Marcy

Some thirteen billion years ago, the most incredible event occurred in history. The Big Bang launched the concepts of time and space in our universe. What that event actually was remains the greatest mystery we can imagine, so great that it makes no sense to ask what came before. That titanic explosion filled space with dark energy and dark matter, the nature of which we don't know. But sprinkled here and there was ordinary matter, distributed not quite uniformly throughout space, a little more in one location and a little less in another. Astronomers detect the light emitted by this patchy material as the "cosmic microwave background" (Fig. 1).

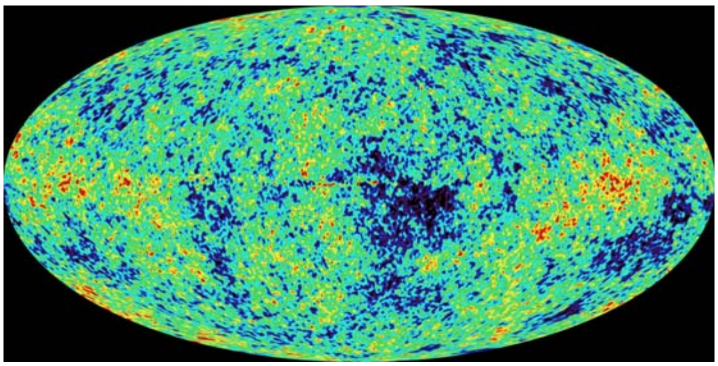

Fig. 1 An all-sky map of the fluctuations in temperature of cosmic microwave background radiation. The red and yellow spots represent hotter areas, while blue patches are colder regions. The amplitudes of these fluctuations are only of orders 10^{-5} of the mean blackbody temperature of about 2.73 K. This shows how uniform the microwave background is over the entire sky, even though most parts had never been in causal contact. The plot is made by the NASA/WMAP Science team based on data obtained by Wilkinson Microwave Anisotropy Probe http://map.gsfc.nasa.gov/.

As the space-time quilt of the universe expanded, the matter cooled and gravitationally collected into clumps, forming galaxies that consist of billions of stars each (Fig. 2). Most of those stars harbor planets, some rocky, some gaseous, and some being mixtures of both with icy mantles. The diversity of worlds transcends the eight samplings that orbit the Sun. My research group, along with the Swiss team, has been fortunate to detect the first 150 of those planets around other stars. On such worlds, the hydrogen, carbon, oxygen, and nitrogen, and myriad other atoms all obeyed the universal principles of physics, chemistry, and mathematics. The atoms moved, reoriented themselves, and interacted with energy without making choices and without guidance.

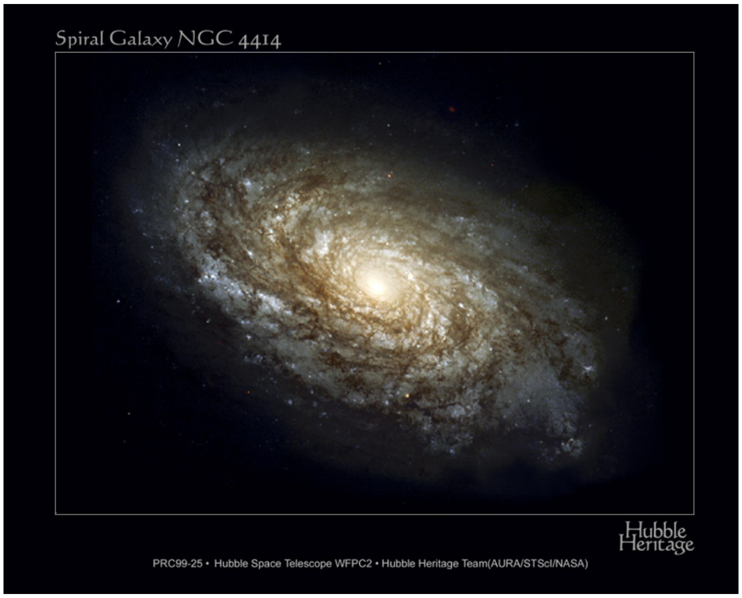

Fig. 2 Galaxy NGC 4414, a typical spiral galaxy similar to our own galaxy, the Milky Way. Image credit: NASA/STScI.

The atoms bonded to each other into larger and larger molecules, some eventually capable of replicating themselves chemically. These replications perpetuated themselves and competed for both the remaining molecules and for the available energy needed to break and reassemble them. The most successful of them developed molecular sheaths for protection, communication, and molecular commerce. Some membranes engaged in charge-exchange to communicate with neighbors, making the first neurons, the networks of which we call brains. One network has developed so prodigiously that it asks about the origin of the universe and of itself. It also wonders if other networks exist elsewhere.

Similar questions were asked by the great Greek philosophers, Democritus, Aristotle, and Epicurus. In 400 BC, Democritus wrote,

"There are innumerable worlds of different sizes. These worlds are at irregular distances, more in one direction and less in another, and some are flourishing, others declining. Here they come into being, there they die, and they are destroyed by collision with one another. Some of the worlds have no animal or vegetable life nor any water."

The modern Greek government recently honored Democritus by putting his picture on a postage stamp (Fig.3). In 300 BC, Epicurus working in Athens wrote,
"There are infinite worlds both like and unlike this world of ours ... we must believe that in all worlds there are living creatures and plants and other things we see in this world."

These writings were forgotten for nearly 2000 years, until Giordano Bruno revived them with his book, "De l'infinito, universo e mondi" (The Infinity, the Universe and Its

Worlds) published in 1584. In it, Bruno actively supported the Copernican theory that the planets circle the Sun and he speculated about the enormous numbers of planets around other stars, some of which, he deduced, must have life. On February 17, 1600, the Catholic church burned him at the stake for his audacious, uncompromising attitude.

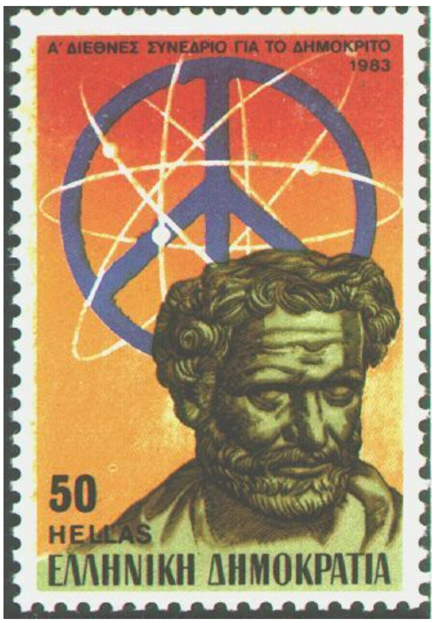

Fig. 3 A stamp issued by the Greek Government to honor Democritus.

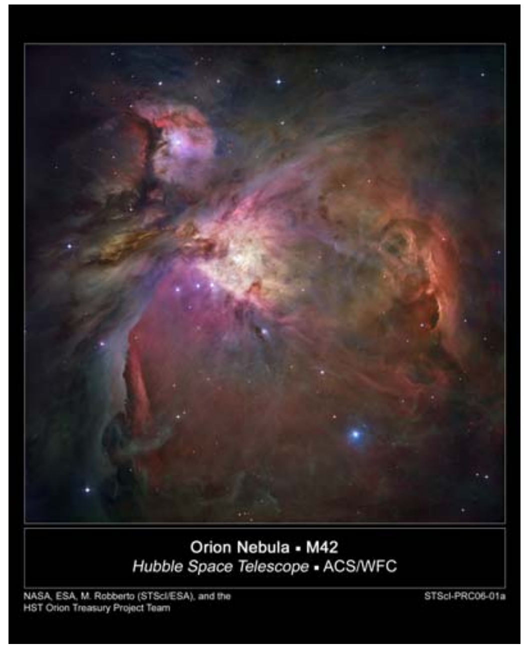

Fig. 4 The Orion Nebula, site of the births of many new stars and planets. Image credit: NASA, ESA, M. Robberto(STScI/ESA), and the Hubble Space Telescope Orion Treasury Project Team.

We now know that Democritus, Epicurus, and Bruno were asking the right questions. Looking at the Orion nebula, we see thousands of young stars being born, each a mere one million years old (Fig. 4). At least 80% of these nascent stars have swirling gas and dust orbiting them, surely the sites of planet formation in progress. The dust particles collide and stick, forming ever larger dust bunnies, eventually growing into larger and larger fractal balls of rock and ice. These ice-laden planetary embryos also collide and stick, growing to the sizes of moons and planets. The craters on our Moon (Fig. 5) serve as fossil testimony of that era of heavy bombardment in our Solar System. The Earth received even heavier bombardment than the moon, due to its gravitational attraction of wayward embryos.

Fig. 5 Craters on Moon.

But there is another remarkable constituent of the gaseous Orion nebula: water. In all stellar nurseries where stars form from the ubiquitous hydrogen and helium gas, some hydrogen atoms bond to oxygen to make H_2O. Indeed, radio telescopes, such as the SWAS satellite, reveal oceans of water wafting within the Orion nebula. This water eventually collects on comets and asteroids that in turn fall onto the planets themselves, supplying the ponds, lakes, and oceans on those young worlds. The Earth is certainly not an unusual planet in having water.

Still, we do not know how commonly habitable worlds occur. To be sure, a majority of stars have planets with hard, rocky surfaces to serve as the petri dishes for early biochemistry. But many such planets (perhaps most) are probably covered with dry deserts similar to Mars (Fig. 6) or are blasted by impacts and radiation similar to Mercury. Other rocky planets may suffer from unbearably high temperatures of hundreds of degrees Celsius, due to the runaway greenhouse effect. Complex organic molecules are unlikely to survive, never mind delicate synapses. Many worlds may be covered entirely by a thick ocean, leaving no continents on which life can get a toe-hold. On all such environmentally challenged worlds, the advancement of species may be severely limited. Dry deserts and waterworlds may not sprout a tree of life as rich as that here on Earth.

Fig. 6 The surface of Mars is covered with dry deserts. The image is taken by the Mars Pathfinder Mission. Image credit: NASA/JPL.

The wonderful goal for the upcoming century is to discover the full array of properties of other worlds. What is the range of geological processes, of atmospheric composition, of ocean types, and of biochemistry on other worlds? Is the Earth a rarity, with its tectonics, carbon cycle, stabilizing moon, and exquisite, long-lasting complement of water? Characterizing the diversity of worlds around other stars will require enormous telescopes in space, capable of blocking out the glare of the host star to allow the light from any planets to shine through. The reflected and thermal light from such planets will carry strong messages about the nature of those planets. The variations in reflected light as the planet rotates will tell us the surface coverage of continents versus oceans and of clouds versus deserts. The spectral rainbow of colors from new worlds will reveal the chemical composition of the rocks, atmospheres, and the biological activity, if any.

To begin this telescopic quest, the nations back on Earth should combine their resources to build these great space-born observatories. We may hope that NASA, ESA, China, Japan, Canada, India, Russia and other nations will collaboratively build a space-born "Planet Analyzer Telescope" that can detect and discern the spectral messages contained in the light from other exoplanets. The current crop of missions, called Kepler, SIM-PlanetQuest, Darwin, and the Terrestrial Planet Finder will discover the rocky planets and measure their masses, radii, and chemical compositions, with a goal toward assessing habitability. Our Doppler team, along with the Geneva Doppler team led by Michel Mayor, will make ultra-precise measurements of the wobble of other stars, to detect rocky planets orbiting within 1 Earth-Sun distance of the nearest stars. (We still need funds to operate this rocky planet search.) From those planets that transit their star, we will learn their diameters, as well as their masses, hence determining the densities of those rocky worlds (Fig. 7). The planet's density in turn will tell us the admixture of rock and water. We will know, within a few years, if rocky planets are common and whether they are occasionally laden with heavy oceans or not.

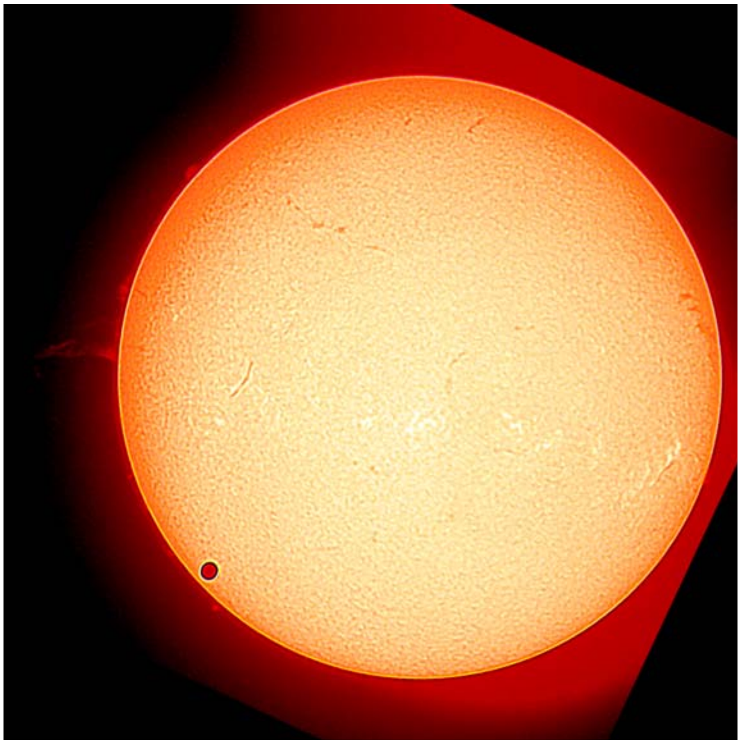

Fig. 7 Venus Transit of 2004. When a planet moves in between its star and Earth, a transit occurs, and the planet blocks off a fraction of the star's light.

Meanwhile, several groups in the world continue the search for radio and optical signals from intelligent civilizations. Futuristically, the University of California at Berkeley and the SETI Institute are jointly building an enormous array of 350 radio dishes (funded by Paul Allen, the National Science Foundation, and by others) designed to detect the radio-wave transmissions from technological civilizations that are broadcasting toward us, for whatever reason. If we successfully eavesdrop on another intelligent species in our Universe, it would bring humanity to a standstill, frozen in awe.

Why do we humans search at all for planets and life in the universe? Some would answer that we have an inner yearning to explore our environment on the grandest stage and to understand our origins, going back to the big bang. Some would appreciate a cosmic picture album of our natural history, going back before the australopithecine clambered out of the East African savannah, before the first cell walls formed, and before the Earth coagulated 4.6 billions years ago. How did the universe turn a cosmic fireball into clever folks, who are now preparing to genetically engineer themselves?

Perhaps the cosmic picture album will tell us whether we Homo Sapiens are merely a chance quirk of nature or the inexorable outcome of Darwinian evolution. Are we humans really so special?

If other smart folks are out there, some of them may be searching for us. If so, imagine that you are an alien space traveler entering our Solar System in your spacecraft, after a long journey at nearly light speed through the blackness of interstellar space. Through your windshield you see in the distance a tiny yellow dot orbited by eight large planets and also numerous icy comets and small asteroidal debris. Some planets are gray, some red, some greenish, and some brown. But one is remarkably blueish with streaks of white (Fig. 8). You know that the blueish planet holds some promise.

Fig. 8 Earth. Image credit: NASA/MODIS/USGS.

Fig. 9 Venus. The planet is covered with thick clouds and a dense atmosphere dominated by CO_2. It is believed that runaway Greenhouse effect heats up the surface of Venus to over 400 ^oC. Image credit: NASA/STScI.

Using your gentle propulsion system, you ease toward the interesting blue planet. Keeping a safe distance, you adhere to Galactic ethics, "Look, but do not disturb."

What do you learn of Earth from afar? You guess that the blue color is due to water, and that it apparently covers 2/3 of the surface. You take a spectrum, confirming the H_2O. You take another spectrum of the atmosphere, detecting oxygen, both O_2 (in optical light) and ozone (in infrared light). You immediately have a clue. Oxygen is unlikely to exist in such abundance just naturally because it reacts chemically with rocks to make rust. You immediately hypothesize that something is alive on that planet that creates and replenishes the oxygen. A further guess would be that plants are doing the job, by the common Galactic process of photosynthesis.

Your spectra also reveal ozone, which you realize immediately is important for the survival of life, protecting it from deadly UV rays coming from the Sun. But this ozone represents a chicken and egg problem. Life is endangered by incoming ultraviolet light without the protective ozone, but it is life that produces the protective oxygen. What came first, life or oxygen? This is an exercise for the young alien student, perhaps for a Ph.D. dissertation. Mysteries about the onset and evolution of life must surely intrigue curious, young neural networks throughout the Galaxy, if indeed they are common.

Your spectra of the blue planet also reveal carbon dioxide and methane: greenhouse gases, well known to civilizations throughout the Galaxy. You realize that these gases keep the Earth warm and you notice that the CO_2 abundance is precariously balanced. Less CO_2 and the earth freezes. But more CO_2 and the Earth heats up, driving CO_2 out of the oceans and silicate rocks which would accentuate the greenhouse effect, heating the Earth even further. Quickly the Earth would suffer a runaway greenhouse effect, heating it to 600 F, similar to Venus (Fig. 9).

As a sympathetic alien, this environmental balancing act reminds you of a marble resting on top of a hill. A small nudge leaves the marble near the hilltop, but larger perturbations will cause it to roll off, never to return. Indeed, the Great Galactic Library, if such exists, probably contains numerous examples of great technological civilizations that revved their engines too far and could not prevent a greenhouse runaway.

In your study of this blue planet, you would detect radio and TV waves, emitted at specific frequencies. You deduce that a very elementary species has achieved radio technology - a newbie in the Galactic Radio Club. Of course, we humans have been transmitting strong radio and television programs inadvertently outward from Earth since the 1940's. Traveling at the speed of light, 300,000 kilometers per second, our first radio transmissions have gone 65 light years from Earth in all directions, and wash over 1000 star systems.

If intelligent civilizations detect our TV programs, what must they think of us? They would catch the most popular programs such as "reality TV" shows in fraternities and many murders among humans, solved by tough law enforcement officers. They would learn of our technological advances in sophisticated weapons, video games, and cosmetic surgery. From news programs, they would learn of our religious and racial differences that sustain never-ending conflicts. They would learn of our growing human population and our over-use of resources unsustainably and without a global plan. An advanced alien being would pause quizzically upon learning of these human activities.

We can't call those TV programs back. They're already streaming away from Earth at the speed of light. If the nearest intelligent civilization resides many hundreds of light years away, our reputation is OK for a while.

Indeed, it is peculiar that advanced aliens haven't noticed us already. If they reside within a few hundred light years, and are more advanced by a few measly millions of years, they could have sent numerous robotic probes to Earth or even come here themselves. Before we Homo Sapiens arrived on the scene only 2 million years ago, advanced civilizations could have sent probes to Earth, set up monitoring stations, and even established vacation resorts here on the lush Earth. But they didn't. Where are all those advanced civilizations that supposedly buzz around the Galaxy according to science fiction writers?

Perhaps advanced civilizations are actually more rare than we think, not because they don't form, but because they don't last long. Perhaps civilizations arise occasionally on the billions of habitable planets within our Galaxy. But perhaps technology destabilizes the social and natural environments that functioned properly during the infancy of a society's existence. Maybe only a small fraction of technological species survive against their growing appetite for energy resources, their environmental degradation, or their nuclear and biological wars. Or perhaps they evolve inexorably into video-game devotees, content to fantasize about space travel, but not actually do it.

Indeed, where does our propensity for technology come from? We humans still carry questionable evolutionary baggage, including a predisposition toward home-village superiority, obedience to authority, religious righteousness, and a distrust of people different from us. We often sense a threat from those having a different racial, religious, sexual, or educational orientation. The animosity that fans of one sports team feel toward those of another team shows how vulnerable we humans are to disrespect for the other. And no one seems to like the umpires. This predisposition to find "evil" in others surely threatens our survival as a species. Historically, when one village attacked another, the devastating outcome affected only a few. But today such aggressive tendencies threaten the whole planet. Our evolutionary baggage was never flight-tested for global conflict.

But we humans have some lovely attributes too that may help us survive. We quickly feel empathy for the plight of others and we dearly appreciate nurturing our young, imbuing them with a yearning to learn, succeed, and to remain curious. Our intellectual capacity for self-inspection may help us recognize and counteract the harmful evolutionary baggage. None of us can know whether humanity will survive for another hundred, thousand, or million years, as our complex inner conflicts play out. Fears are stoked further by politicians and news media who warn us of the enemy-du-jour.

Viewed from far beyond our home Solar System, the Earth seems precious and fragile. National boundaries seem arbitrary and ephemeral, defended by those who happened to be born within one or the other, during one century of the other. Wealth, property, and religious feelings vanish when a brief lifetime ends. Our collective spending of funds toward weapons rather than toward conflict resolution and peace-preserving principles seems pointless as each war fades from memory and another emerges. The potential penalty for our short-sightedness grows yearly with our advancing technology.

If we live in a "small world after all" and a "global village", where is the council of elders who speak for our global well-being? Where is the long-range planning commission to provide guidance for our international policies that affect everyone? Who represents the unborn generations, as we exhaust their resources today? Why, after thousands of years of wars, is there no internationally respected set of preconditions that justify going to war, with which the world could pass judgment and respond uniformly? Doesn't humanity need some revitalized organization similar to the United Nations? Or will we simply throw the dice with human survival every time a powerful national leader feels threatened?

Compared to the history and expanse of our Universe, we humans of any generation are like last spring's butterflies - glorious but ephemeral creatures who live out our entire lives in blink of an eye. We five billion humans each have a chance, during our brief lives, to thrive and cling precariously to our tiny habitable world that is surrounded by the enormous cold darkness of the universe. What we do with our planet, its environment, and our international social structures, will powerfully set the stage for our descendents and the fate of our species. There may be no grander way to honor the beauty of nature than to promote our global cooperation and to explore our connections to other worlds and life elsewhere in the universe.

With acknowledgement and appreciation to Carl Sagan whose ideas are represented here.

Geoff Marcy
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