GREG MATLOFF • C BANGS • LES JOHNSON

Harvesting Space for a Greener Earth

Second Edition

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Dedicated To
My children, Carl and Leslie
The future I am so dedicated to preserving belongs to them.

Les Johnson

Mother Nature, may she always be whole!

Greg Matloff

The Earth and my parents, who bequeathed to me their love for her.

C Bangs

Foreword (From the First Edition)

Gloom and doom sells. That salient point is made by the authors and, for me, is reinforced every time I sit down in front of my favorite cable news channel. Mass shooting at a high school in lowa. The glaciers are still melting. Terrorists attack a hotel in Pakistan. The whales are going extinct. We hear about loose nukes, lunatics in power, corrupt politicians, child abuse, famines in Africa, tidal waves in Thailand, and so on. A woman in the Middle East is raped; then she is accused of immorality for allowing the attack to happen, and is murdered. Racial conflict shows up in Cambridge, MA. News arrives every day that the United States may sink under its accumulation of debt. And we all know the world is running out of oil.

Despite all this, the authors point out that things have been worse. At the turn of the last century, people in the United States were, on average, not living much past 40. One thinks of the pre-Civil Rights era, of the Depression, of the nuclear confrontation between the superpowers over Cuba. I can recall, during those years, watching workers build an overpass on the Baltimore-Washington Expressway, and wondering why they bothered. At that time, an eventual all-out war seemed inevitable.

Harvesting Space for a Greener Earth has three authors: Greg Matloff, a physicist at the New York City College of Technology; his wife, C Bangs, a Brooklyn artist; and NASA physicist Les Johnson.

Matloff is convinced that science and intelligence will eventually win out over the lunacy that has plagued humankind since Herodotus was writing history. He has published more than a hundred scientific papers, and is the author of, or collaborator on, seven other science books.

Bangs's work might be said to be inspired by starlight. She uses Gaia, goddesses, and the night sky to portray various aspects of the cosmos. Her conversations with her husband about life, death, and the universe provide much of the insight on display in her art. Les Johnson has managed various in-space propulsion technology projects for NASA. He's worked on a tether experiment using Earth's magnetic field for propulsion. And he has twice received NASA's Exceptional Achievement Medal.

In *Harvesting Space for a Greener Earth,* the authors recognize the severity of the problems that humanity faces, and they don't pretend that technological breakthroughs alone will be enough to save us. But it is clear that, without the technology, we are headed for a catastrophe.

And there is reason for optimism. After all, life is getting better. We live more comfortably than our grandparents did. It is now possible that African-American neighbors can show up in the neighborhood without unduly alarming those who really like the nineteenth century. We now have the Internet; we are showing signs of getting rid of tobacco, and medical science has come a long way. And we've developed a global sensitivity that we never really had before.

The authors suggest that the growing awareness that we share the same world, and that it has its limitations, began with those first photos of Earth taken from the Moon, the pictures of the fragile blue world drifting through an endless sky. They're probably right. If the human race ever does really coalesce into a family, I suspect those pictures will be hanging near the front door of the family estate.

Will it ever happen? Bangs, Matloff, and Johnson think it will. And, in *Harvesting Space for a Greener Earth,* they lay out a plan to make it possible. If we choose to make the effort, to collaborate, to work together, here, they say, are the tools we will need. Here's how to deal with the inevitable energy shortages that are on the horizon, and do it in a way that does not wreck the ecosystem. They point out that we have a virtually infinite supply of clean energy available, compliments of the Sun. All we need do is make the investment to harness it.

Here also is a technique for getting rid of the pollution caused by various manufacturing industries. And we might also want to take a long look at the dangers presented by near-Earth asteroids. A single rock, a mile or so in diameter, could put the lights out for all of us. Permanently. Most people shrug at the scenario. They would ask how many of them are there? The answer, unfortunately, is that they are numerous. And they are all over the place. Two weeks ago, as I write this, something very large crashed into Jupiter. We never saw it coming.

Then there are the issues of global warming. And conservation of resources. With world population at 6 billion and climbing, recycling aluminum cans, planting more trees, and turning the air conditioner down a notch won't get the job done. Wont' come close. We're face with serious problems, and eventually both will reach the crisis stage.

Do the authors have a plan? You bet! It's not a solution we could manage today, because we don't have the technology yet. But there's time. If we act. If we avoid our usual propensity of waiting until the flood waters are running into the valley. And that's the problem with the plan. It will require politicaI will and advance planning. And maybe, most important of all, imagination.

I'd like very much to see a copy of *Harvesting Space for a Greener Earth* placed in the hands of leaders, and talk show hosts, around the world. The rest of us will be able to profit by it, too.

Jack McDevitt
Nebula-winning author of Time Travelers Never Die

Preface

A lot has happened since the first edition of this volume was published in 2010. First, the order of authors has changed. That's because Greg Matloff elected to take early retirement from his full-time teaching position at New York City College of Technology and Les Johnson's responsibilities at the NASA Marshall Space Flight Center have expanded.

After the publication of the first edition, artist C Bangs created with Greg Matloff's collaboration an artist's book *Biosphere Extension: Solar System Resources for the Earth*, which has been collected by the Brooklyn Museum and the British Interplanetary Society. Some of the art from that volume has been modified to appear as chapter frontispiece art in this edition.

The concept of applying solar system resources to improve terrestrial existence seems a bit more immediate in 2013 because of the increased number of private and public players in the space arena. Diverting Earth-threatening asteroids using our developing interplanetary capabilities has taken on fresh urgency after the 2013 air burst over Siberia that injured about 1,500 people but happily resulted in no fatalities.

Colleagues of ours affiliated with Oak Ridge National Laboratory in Tennessee who authored a chapter in the first edition discussing a space-based approach to alleviating global warming have expanded their efforts to contribute an additional chapter to this second edition on suggested Earth-based approaches to deal with this global issue.

Perhaps the failure of many world governments to adequately address this urgent problem is a cause for pessimism. But such pessimism might be countered by the fact that application of green energy is increasing on our planet.

No one can predict the outcome of the multiple current world crises. But solar system resources can certainly be applied to alleviate some of these problems if we have the will to tap them. It is hoped that the ideas presented in this volume contribute to a positive future for humans and all terrestrial life.

Brooklyn, NY, USA — Greg Matloff
Brooklyn, NY, USA — C Bangs
Madison, AL, USA — Les Johnson

Acknowledgements

We would like to thank Ken Roy, Robert Kennedy, David Fields, and Eric Hughes for their contributions to Chaps. 15 and 16, where they discuss various approaches to mitigate the effects of global warming by geoengineering. We are blessed to have such technically innovative thinkers as both colleagues and friends. We also appreciate the editorial assistance of Maury Solomon and Nora Rawn of the New York Springer office.

Thanks also to Mitzi Adams and Sam Lightfoot for providing their technical expertise in reviewing Chaps. 4 and 6.

We appreciate our colleagues, friends, and students, who have been a constant source of inspiration.

I (Les Johnson) would like to thank Stuart and Dolores Peck for allowing me to use their spare room so that I could have a quiet place to write on Wednesday nights. I also appreciate the constant supply of ice cream they provided. A person could not have better in-laws!

Some of the chapter frontispieces utilize C Bangs's photographs of exhibits in the Hall of Human Evolution at the American Museum of Natural History in New York City.

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About the Authors

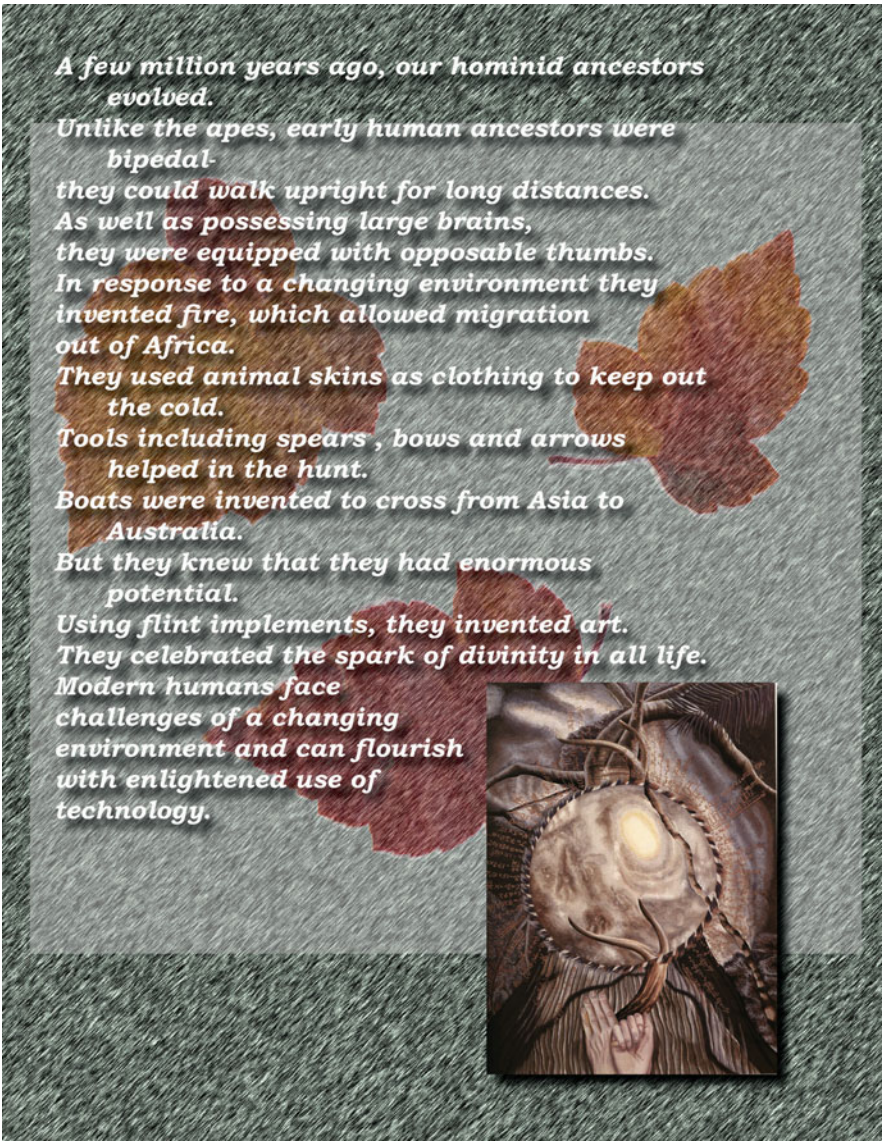
Greg Matloff has published or delivered about 100 research papers related to atmospheric physics, space exploration, and space science and has authored or co-authored nine books and many popular articles. Dr. Matloff is a professor emeritus and adjunct professor at New York City College of Technology, CUNY, where he teaches astronomy. Matloff consulted for NASA Marshall Space Flight Center; he is a member of the International Academy of Astronautics, a fellow of the British Interplanetary Society and a Hayden Associate at the American Museum of Natural History, where he worked on asteroid diversion techniques. He also heads the science board on the new Institute for Interstellar Studies.

C Bangs has exhibited her art in museums and galleries throughout the United States, South America, Europe and Australia. Bangs has created chapter frontispiece art for the books authored by her husband, Greg Matloff. Reversing roles with Greg, she created her first artist/scientist book, which has been collected by the Brooklyn Museum and the British Interplanetary Society for their artist book collections. Her work has appeared in the *Journal of the British Interplanetary Society, Analog: Science Fact and Fiction* and *Zenit*. Bangs worked under a grant at NASA Marshall Space Flight Center and then as a NASA faculty fellow for three sequential summers. Bangs' art is included in numerous public and private collections.

Les Johnson is the deputy manager of NASA's Advanced Concepts at the Marshall Space Flight Center in Huntsville, Alabama. Previously he managed NASA's In-Space Propulsion Technology Project, developing advanced technologies such as solar sails and aerocapture for future space science missions. He was the NASA co-investigator on the Japanese T-Rex tether propulsion experiment in 2010. In addition to his NASA credentials, Johnson is also an inventor. He holds three patents and was twice the recipient of NASA's Exceptional Achievement Medal. He is the author of numerous technical publications, co-author of three mass-market popular science books and two science fiction books and has consulted on various novels and two major motion pictures.

Part I
Mythical Paradise

Chapter 1
Introduction: Welcome to the Present



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Pre-Technology Humans

"I know a bank where the wild thyme blows,Where oxlips and the nodding violet grows;Quite over-canopied with luscious woodbane,With sweet musk-roses and with eglantine"—
William Shakespeare, from *A Midsummer Night's Dream*

If you are reading this book, you are most likely a member of the most privileged generation in humanity's experience. You have a roof over your head—a vast improvement over the lot of many of our ancestors and a significant number of humans today. You have access to good health-care facilities and can count on between 70 and 80 good years.

Clean water is yours at the twist of a knob. And food—as healthful or exotic as you might desire—is available a short walk, subway ride, or drive from your front door. Your great grandparents might have sacrificed a great deal for these advantages alone.

Education, although not universal, is widespread. In all likelihood, you have a moderately creative and financially rewarding professional life, also a great rarity before about 1950. If you push a button, entertainment and information from the world over can flood your consciousness. You can even remain connected to this planet-wide information network as you walk in a park, cook your dinner, or ride in a car.

However, serious problems loom on our horizon, problems that threaten to swamp our envious situation. The world's population continues to expand. And surprisingly to some, the burgeoning populations of Asia, Africa,, and South America desire the same advantages enjoyed for many years by North Americans, Europeans, the Japanese, and Australians.

Can contemporary civilization provide for billions of more humans living as well as we do? Where will the energy come from? How do we deal with the pollution? Will carbon dioxide emissions and other human-produced greenhouse gases evoke long-lasting climate change that will increase global temperatures, raise sea levels, and swamp coastal lands?

A million years ago, as our ancestors began to emerge in the park-like savannah of central Africa, a response developed to the problem of environmental degradation. When your local environment was exhausted, move! This worked well as hunter-gatherers moved around the globe and civilizations developed and spread. The world is littered with the ruins of once-great cities surrounded by degraded environments.

However, today there is nowhere to flee. Civilized humans are everywhere on Earth. Early science-fiction authors hoped for benign climates on neighboring worlds, but none of these worlds could sustain more than a tiny fraction of the human population, and that at great expense. Even if people were genetically modified with gills to live in the oceans, this would be a mere stopgap measure; the oceans are not immune to human pollution.

Conservation, limiting growth, and recycling can provide some relief, but any such relief will almost certainly be only temporary. With the rest of the world's economies growing into variations of our capitalistic one, it is only a matter of time before we simply run out of resources, energy, and places to store our waste. This does not mean we should not conserve, limit growth, and recycle! On the contrary,

these measures are essential to the survival of our civilization and, potentially, our species. They are simply insufficient to resolve the core issue we face—that Earth cannot by itself indefinitely sustain a worldwide population of consumers. It is impossible to recycle with 100 % efficiency; to limit growth to "no growth," or to conserve into prosperity.

It was a bitter cold day in December 1968 when humans in general became aware of their kinship as riders on a fragile, living Earth. From a quarter-million miles away, the crew of *Apollo 8* pointed their cameras homeward after they had safely settled into humanity's first orbit of the Moon.

The view of the desolate Moon was striking on our television screens, and the astronauts' scripted reading from Genesis was stirring. But it was the shimmering, living, marble-sized Earth, hanging in stark contrast above the stark lunar horizon, that would profoundly alter our view of ourselves and our world.

Living worlds are fragile and delicate. And space is very, very large. This lesson would be repeated and amplified in 1990 when on the edge of the galactic void, the cameras of *Voyager 1* were focused back on our planet. From its multi-billion-mile vantage point, *Voyager* imaged Earth as a pale blue dot almost lost in the glare of the distant Sun. Earth is a seemingly unique abode for life in an otherwise empty and apparently lifeless expanse of nothingness.

So as you escape our increasingly urbanized world to stroll through your local park, botanical garden, or forest and gain spiritual sustenance from your temporary immersion in this sanitized (predator-free) version of our original environment, you might well ponder the troubled legacy of our golden age. Planets abound in our galaxy, but planetary ecospheres are rare and precious.

Will the parks of Earth survive this age of over-population, resource consumption, nuclear proliferation and terrorism? Or will our civilization go down with a bang or a whimper, to be remembered in legend by a remnant population eking out a living in a depleted, contaminated landscape?

No one can know the answer to this question. But there is hope within the gloom. An optimistic scenario exists if contemporary humans are collectively wise enough to grasp the opportunities of the present. Although the modern environmental movement applies much-needed first aid to our resource and environmental challenges, we can simply look up for the potential cure—space harbors enough resources to meet the needs of an ever-more prosperous humanity for millennia. Space is an environment generally hostile to life that can be used to house industries whose byproducts are also antithetical to life, and nearly infinite energy.

Our Solar System is very rich in energy and resources and can even serve as a sink for some of the unavoidable effluents of technological society. Further, to avoid the fate of the dinosaurs, humans may decide to use our revived interplanetary capabilities to alter the solar orbits of those kilometer-sized chunks of cosmic rock and ice that occasionally wallop Earth. And if we can move these objects around, perhaps we can mine some of them.

Even if interplanetary space can never absorb more than a handful of Earth's living inhabitants, its resources can be used for the betterment of life. Envision a future where plentiful energy comes from the Sun, industrial pollution is virtually

removed from the ecosphere, and no country needs to suffer from a lack of natural resources. Then, the 10- to 15-billion peak human population on Planet Earth can enjoy comfortable, productive lives. And the parks of Earth, the thyme and violets, need not die.

This book is divided into three parts. Part I, Mythical Paradise, reviews current scientific thinking about how Earth came to exist and how life arose. Many consider primitive Earth, the planet as it was before the rise of human civilization, to be a paradise lost. In reality, it was a hostile environment in which only the strongest survived, and it was far from being a paradise.

Part II, Paradise Lost?, describes the rise of human civilization, our progress from simple, daily survival to where we are today—with many humans living long, productive, and meaningful lives—and the associated (mostly negative) impacts to the environment that our civilization has wrought. It is here that we outline the challenges our twenty-first century civilization faces.

Part III, Sky Harvest, describes how space and space technologies can be used to monitor the global environment, help undo ecological damage, and prevent further damage to Earth's ecology upon which we all depend.

The first edition of this book was published in 2010 under the title *Paradise Regained: The Regreening of Earth*. In a few short years, a lot has happened that affects the issues discussed in this book.

On one hand, a lingering global economic crisis and unending regional wars have led to widespread doubt regarding the ability of national leaders and the international community to successfully address the complex issues facing us. This, in turn, has led to widespread pessimism about our future prospects.

On the other hand, we have witnessed the rise of commercial space enterprises. Traveling in space, exploring this vast domain and ultimately exploiting the resources that abound there need not be the exclusive domain of governments and international consortiums.

The survival and advancement of our now-global civilization presents us with major challenges. Nevertheless, we should try to preserve optimism and press ahead with the job. Above all else, we should not lose heart! If this book helps to restore hope for an expansive, prosperous future for humanity, it has succeeded.

Chapter 2
Space Utilization: A Moral Imperative

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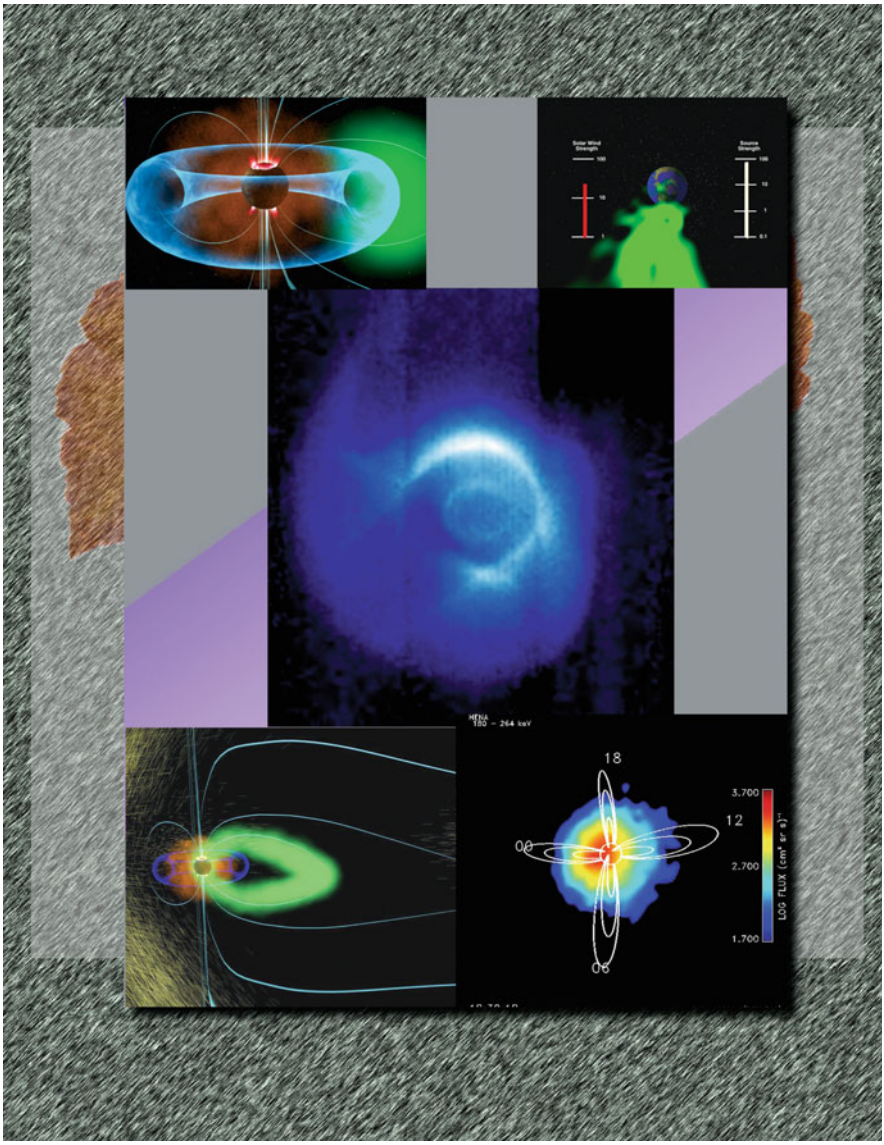
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"I saw the sudden sky
Cities in crumbling sand;
The stars fall wheeling by;
The lion roaring stand."
—From the poem "The Lion" by W. J. Turner

As citizens of the already-developed countries of the world grapple with their impact on the planet, so do those living in the rising economies of China, India, and Africa. But although it is relatively easy for those of us in the developed world to say we will make due with less consumption for the good of the planet, those in the developing world don't have that luxury. They need to consume more resources to have jobs, educate and feed their children, and to generally improve their quality of life. On a per capita basis, they don't want or need to be as profligate in their use of the world's resources as we've been, but there are so many of them that each using only using a small fraction (as compared to residents of North America, Europe, and Japan) of what their developed counterparts use will place dramatically increased stress on the global environment and the planet's resources.

Space advocates and environmentalists are cut from the same cloth. They have very similar long-term goals and the same basic moral principles guiding them. Life on Earth is precious; it must be preserved and protected for future generations of the planet's inhabitants, both human and nonhuman. Unfortunately, as we look at the challenges posed by rampant materialism, increased production (using up the planet's resources), and the commensurate increased pollution from the developing world, these two groups tend to take very different approaches to addressing these core problems. Worse yet, each group tends to view the other with suspicion and questions their motives and tactics. Space advocates tend to believe the environmentalists are motived by a political and economic agenda (tending toward the political left), while environmentalists tend to believe that space advocates are part of the military/industrial complex following a right-wing political agenda. Both are simplistic generalizations. If the two groups are serious about saving the planet then they need to put aside their political differences and work together. Environmentalists are working to stop very real and immediate environmental damage, but they don't have a long-term plan for saving the planet. Space advocates have the long-term solution to environmental stresses on the planet—the use of space resources—but tend to ignore what can be done in the short term, to buy time until the long-term solution can be implemented.

It is this long-term solution that motives the authors to write this book. We mirror the divide described above, with at least one of us leaning politically left and the other politically right. Yet we agree that must act now and plan for the future, if life on Earth is to have a chance. And we must work together on a just and moral foundation.

Since there have been people around to consider the notion philosophers and theologians have debated what constitutes morality. The word *morality* comes from Latin and refers to our notion of what constitutes right and wrong or good and evil. What constitutes a moral action varies dramatically from culture to culture, though

many cultures share some common thought as to what is right and wrong. For example, most modern cultures believe that murder is not a morally acceptable method to settle a dispute and that theft is not a moral act. But even these seemingly simple moral judgments are far from universal, and anthropologists can undoubtedly find cultures on the globe that do not share these views.

We will put forth a moral concept upon which this book will stand. It is a concept that should have nearly universal appeal and should guide much of our decision making regarding both space and environmental policies. The moral statement that drives our thesis is deceptively simple. In fact, it is so simple that an entire company is built around it as both a trademark and a pithy statement: Life is Good™. The converse is also a moral assertion—that which leads to non-life is evil. And by "life" we mean communal life, not that of an individual animal or plant, although in the case of humans we believe the assertion is valid almost 100 % of the time. Those who seek to preserve life, human and nonhuman, are acting in a morally superior manner compared to those who seek to diminish or harm life. Often we must act on this moral principle in such a way that some life is harmed along the way to a more global solution that greatly preserves or improves the quality of life in general. These choices must be carefully considered in the context of whether or not they will improve the quality of life or maintain life in the "big picture" or on a scale beyond the immediate and obvious impacts to an individual.

We believe the moral decision that life on Earth is good drives those in the modern environmental movement to their activism. It is this same moral decision that motivates many space enthusiasts, activists, and professionals.

It is a moral declaration to say that life is good and better than non-life. Once this declaration is made, it is easy to see that in order for humans to prosper and be good stewards of the planet and its myriad life forms, they must stop destroying the environment that gives it life. But how do we accomplish this goal and maintain all of the positive aspects that come from our twenty-first-century technological civilization? The answer is pretty simple. We must place heavy industry, with all of its inevitable pollution, in a place that is already hostile to life and in which life will almost certainly never arise—in space or on the Moon. A space-based infrastructure is not only possible but also essential if we are to restore our home planet and turn it into a safe place to live, pollution free. This chapter explores the current environment of near-Earth space, so as to address concerns by some that our presence there will somehow pollute it.

Most of us think of outer space as being empty. If we are comparing space starting at about 200 km above our heads and extending far outward, to what it is like around us on Earth, then *empty* seems to be the appropriate word. For all practical purposes, to most humans, space is empty. (When we refer to space in this context, we are referring to that which is separate and apart from a planet, comet, or asteroid. Of course, the total volume of space occupied by planets, comets, and asteroids is so small in comparison to the rest that it is inconsequential overall.) In space, there is no atmosphere to breathe, no potable water to drink, and not much else in significant quantity—at least from the average human being's perspective.

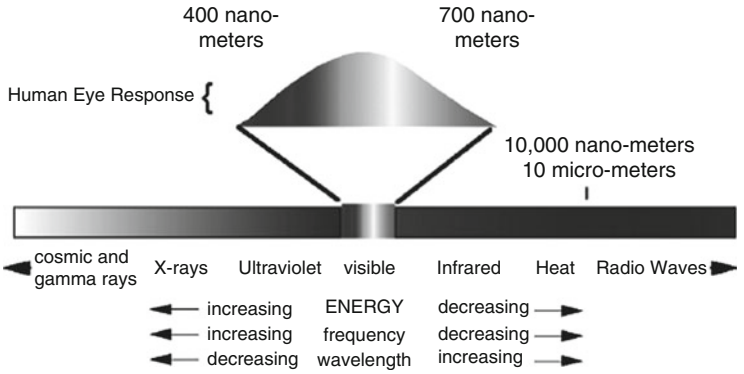

Fig. 2.1 The Sun emits light at many wavelengths, only a small fraction of which can be seen by the human eye. This portion of the spectrum is known as "visible light" (courtesy of the Universities Space Research Association)

However, in the 50 years of space exploration, scientists have learned that space is far from empty, and most of what is found in space is directly antithetical to life. To begin with, the entire Solar System is bathed in sunlight. We depend on the light emitted by the Sun to sustain us. But this light is only a small part of the total electromagnetic radiation ("light") emitted by the Sun. We see only this part because our dense atmosphere filters out most of the rest. The Sun emits light at several wavelengths, from infrared to extreme ultraviolet. The part of the Sun's spectrum that we see is only a very small part of the emitted spectrum and is aptly called "visible light" (Fig. 2.1). By definition, the other parts of the spectrum are invisible to our eyes, but not to our scientific instruments.

Over the past several years, there has been much discussion about solar ultraviolet light. It is this part of the spectrum that causes people to tan and sunburn—in many cases, subsequently causing skin cancers. Fortunately for us, most of the ultraviolet light from the Sun is filtered at high altitudes by atmospheric ozone. There are multiple wavelengths of light that are considered to be part of the ultraviolet spectrum. They are divided into two types: ultraviolet A [UVA] and ultraviolet B [UVB]. The amount of UVB light that penetrates through the atmospheric ozone decreases rapidly with increased ozone concentrations. The converse, unfortunately, also applies: decreased ozone will dramatically increase the amount of UVB reaching the surface of Earth. UVA passes roughly unhindered through the atmosphere.

Since the 1980s, and mostly likely beginning earlier, a global decrease in atmospheric ozone density was observed, with especially large depletions occurring near Earth's poles. The large depleted regions near the poles were dubbed "ozone holes," and their existence was blamed on the human-caused emissions of ozone-depleting chemicals such as chlorofluorocarbons. This depletion was of concern because increased UVB exposure would increase the number of people getting various cancers. It is also thought that increased UVB would do significant harm to plankton in the oceans, with damaging ripple effects felt throughout the food chain that

depends on plankton. Also, several crop species are thought to be UVB sensitive, with death or significantly reduced yields resulting from increased exposure. Global environmental action was taken in the 1990s to reduce human emission of ozone-depleting chemicals so as to mitigate further ozone depletion.

Solar ultraviolet radiation acts as a sterilizer and quickly kills any unprotected life. In fact, ultraviolet sterilization is used commercially to kill bacteria in swimming pools and in air purification systems. In space, there is no atmospheric ozone to filter any of the UVB, and ultraviolet radiation from the Sun is deadly.

In addition to visible and ultraviolet light, the Sun emits many other forms of radiation. High-energy electrons and protons continuously stream from the Sun; this stream is commonly called the solar wind. The Sun emits these particles with velocities between 200 and 800 km/s, depending on where you are relative to the Sun's equator and the solar activity cycle. When these charged particles encounter matter, such as living tissue, they deposit their energy as they slow down and stop therein. These particles have a lot of energy, and the slowing-down process does significant damage to any living tissue in which it occurs. Even short-term exposure to unfiltered sunlight can cause mutations and cancer. Moderate to long-term exposure results in significant cell damage and death.

And it gets worse. In addition to this somewhat steady stream of charged particles coming from the Sun, there are periodic bursts of intense high-energy radiation, called solar energetic particle events, that blast lethal storms of charged particles outward from the Sun to the outermost regions of the Solar System, each packing enough energy to cause human death within minutes to hours of exposure.

Fortunately, our Earth once again protects us from this danger. Earth's relatively strong magnetic field acts as a radiation shield, deflecting all but the most energetic of these particles away from the surface of the planet. (Charged particles, when moving through a magnetic field, experience a force acting on them, in this case, a deflecting force.) Our thick atmosphere, which has the approximate stopping power of 10 m of water or 4 m of concrete, absorbs most of the remainder (Fig. 2.2).

On Earth, we go blithely through our days during these storms, blissfully unaware of the hellish inferno blasting through space a mere few hundred kilometers above our heads.

Across the globe, the average temperature does not vary by much, providing a reasonably stable thermal environment for all sorts of life. Where seasonal variation does occur, life, in general, has adapted to it, growing during the warmer summer months, hibernating during the colder winter months. In author Les Johnson's adopted hometown of Madison, Alabama, the average temperatures range from a low of about 29° Fahrenheit in January to a high of 89° in July. Most residents of north Alabama adapt quite nicely to this range of 60°. Thanks to the complex biosphere of Earth, with enormous oceans and a thick atmosphere to average out and regulate thermal effects, 60° temperature variations in the course of a year are typical for Earth's nontropical, nonpolar regions, which are usually mild and for which life has readily adapted.

In space near Earth, without an atmosphere or ocean, the temperature can vary from +200 to −200°F as quickly as an object moves from being in sunshine to being