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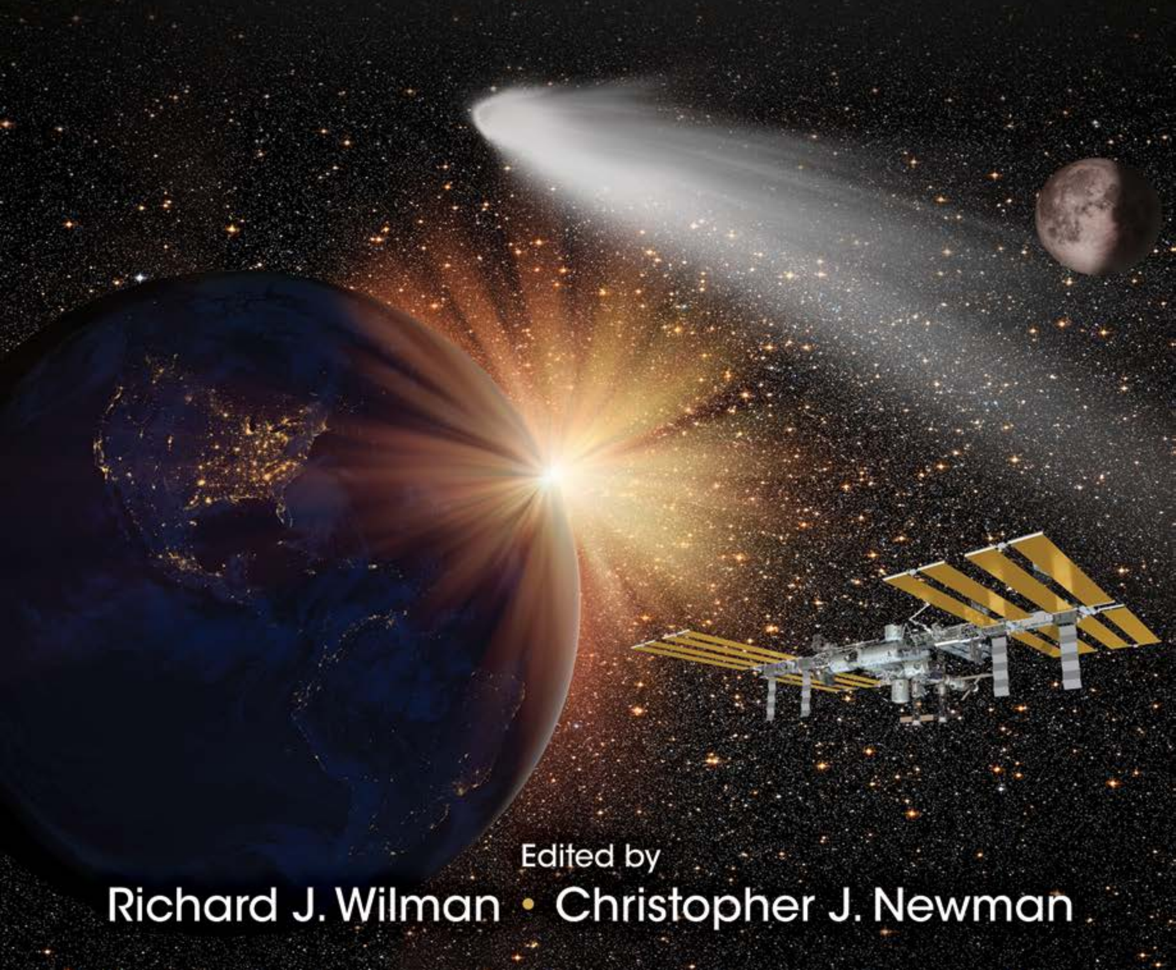
Frontiers of Space Risk

Natural Cosmic Hazards & Societal Challenges



Edited by
Richard J. Wilman • Christopher J. Newman

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The workshop was financed by Durham University's Institute of Hazard, Risk and Resilience, and brought together astronomers, space scientists, engineers, and technology consultants, alongside experts in space law and policy for two days of fruitful discussion. To further explore the workshop themes and related topics, we decided to assemble this interdisciplinary collection. We thank our commissioning editor Francesca McGowan for being receptive to the idea of blending such diverse themes within a single volume, and to Taylor & Francis/CRC's editorial staff Emily Wells and Rebecca Davies for their support and advice along the way. Finally, we thank all of our contributors for providing their chapters, which ultimately brought the book to fruition.

Richard J. Wilman
Christopher J. Newman

Editors

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CHAPTER 1

Introduction

Christopher J. Newman and Richard J. Wilman

CONTENTS

1.1 WHY SPACE RISKS?

The notion of outer space as being a hostile and threatening environment is one which will be familiar to most people. Popular fiction is replete with tales of the dangers posed to the Earth from space (Roberts 2006). More prosaically, the growth in scientific understanding and human space activity since the start of the space race has led to an increased awareness of the dangers posed by an environment inherently hostile to organic human life. Equally, the conceptualization of space as a *frontier* has been identified as a dominant metaphor when considering space as a distinct environment (Billings 2004).* It is a metaphor, which works well as an overarching backdrop for the discussion of the risks, presenting both imagery of new possibilities and limitless opportunities while evoking a sense of physical

* The idea of space as a frontier has been subject to considerable academic inquiry. Although outside the focus of this discussion, the notion of frontier was identified by Billings (2004) as being drawn predominantly from American cultural history, with all of the assumptions and cultural implications that such a worldview brings. For further information, see also McDougall (1985).

danger and hazards. Such dangers lead to risks which can be both natural and human-made, tangible and invisible, and present challenges where the rule of law or its enforcement may be uncertain.

The aim of this book is to offer an introduction concerning how risks from space permeate and circumscribe humanity's increasingly diverse interactions with the space environment. This is underpinned by a widely drawn, multidisciplinary perspective, whereby scientific analysis and engineering solutions are discussed alongside the need for regulatory certainty and clarity in policy making. Fundamentally, as human activity in space increases, and our capacity to explore increases, the risks from such activity will also inevitably increase. As collective awareness of these risks increases, analysis and critique of potential solutions becomes ever more necessary to inform policy makers, embolden academics, and reassure the wider population. The immediate aim of the book is, therefore, to identify and discuss a range of risks coming from the space environment which might impact life on earth.

There are several reasons why such a discussion of risks to the Earth from space is of value. First, these risks that we identify herein will provide an alternate lens through which space activity and the study of space can be viewed and this will be of interest to a wide range of readers. Also, by appreciating the risks facing humanity, policy makers, engineers, and space professionals can decide upon the appropriate resource to dedicate to mitigating these risks. In some cases, where the risk is small, this might mean further resources with which to better understand the phenomenon. In other cases where the risk of occurrence is more likely, it might be that the need for capital expenditure on infrastructure is more pressing. Either way, by viewing risks from space holistically, we hope to provide increased awareness and inform public discourse on these areas. As Bostrom and Ćirković (2008) have already noted in respect of risk, "a broader view allows us to gain perspective and can thereby help us to set wiser priorities."

1.2 SPACE RISKS: FRAMING THE DEBATE

This first chapter will perform several functions. First, as already outlined, it will introduce and explain the value of studying the risks facing humanity from the space environment. In so doing, it is not intended to produce a definitive list of every risk faced by humans. Others have already successfully achieved this in a broader context (see, e.g., Bostrom and Ćirković 2008). Rather, it will reflect upon the nature of risks originating from various sources and how these risks can be categorized. Broadly speaking, these risks are categorized as being either natural cosmic hazards threatening life on Earth or risks that result from human activity in space. In the remainder of this chapter, we will explore these two themes and introduce each of the chapters in turn, to set them within the context of the book as a whole. The chapter will conclude with some final reflections and opportunities for further study.

All of the chapters in the book are written by contributors with a wide range of academic and practical expertise in various aspects of the space environment. Indeed, as can be seen, the contributors to the book are drawn not only from different disciplines, but from different academic traditions and backgrounds. One of the great strengths of such a multidisciplinary approach is the way in which it provides different perspectives on the same problems. Such an approach may lead to different but complementary solutions to the risks posed to humanity on Earth.

Any attempts to delineate between different categories of risks will be inherently arbitrary, nonetheless, there is a need for boundaries to be drawn for the inquiry through which the risks can be viewed and analyzed. It should be noted at the outset that this book purposefully limits itself to the risk to humans on Earth. While there are undoubtedly risks to humans in colonizing other planets and engaging on deep space missions of exploration, these are not likely to be serious ventures for many decades. As such, there are too many variables to make any concrete predictions as to the precise nature of these risks. Similarly, the book will not seek to delve too deeply into the theory of risk management and mitigation. There are numerous excellent specific discussions on this area (Macauley 2005) and consideration is, instead, focused on broader thematic inquiries into identifying the risks from space from a scientific and governance perspective.

1.3 THE CATEGORIES OF SPACE RISK

Having established the initial focus, the book operates from the basic precept that the threats from space to humans on Earth can be broken down into two broadly drawn themes. The first category of risk considered is that which originates from space and threatens all life on Earth. This encompasses the natural hazards arising from our cosmic habitat within the Solar System and the wider Milky Way Galaxy. These risks can be categorized as being naturally occurring (in so far as they are not the product of human activity) although they have the potential to impact both our natural environment and the critical national and global technological infrastructures upon which much of the fabric of the global society depends.

Such dangers are, of course, not limited to those posed by nature. The second broad area of risk comes, therefore, from human activity in space and the societal challenges such activity poses. This theme will encompass technological malfunctions and accidents affecting space hardware and infrastructure. This includes collisions in space due to the proliferation of orbital debris. Risks also stem from the deliberate misuse of space-based assets for the purposes of terrorism or state-based aggression. Such human activity requires an understanding of the attendant risks, and an appropriate mixture of engineering, financial, law, and policy solutions to mitigate them where possible or to maximize resilience.

As stated in Section 1.2 above, we are not primarily interested in technical, practice-based definitions of risk as they might apply to specific industries. We are not seeking to identify the risks purely in terms of scope (the number of those affected) and intensity (the impact of any risk). It is true that should some of the risks identified in the book come to pass then they will undoubtedly prove to be extinction events for life on Earth. Similarly, we are not interested in the precise quantification of risks, in the sense of identifying only those that fall within a certain range of probability; indeed, some of the risks identified may be considered highly likely, while for others the probability of occurrence is so small as to be negligible on timescales of human interest. All of these would provide unnecessary limitations on what is intended to be an exploration of a wide range of ideas.

1.4 THEMES WITHIN THE BOOK

As stated above, we did not impose a series of preconceived limitations based around qualitative categories of risk for authors to follow. Rather, we allowed those with the expertise in specific areas to identify the areas of risk and explore them independently, allowing each discrete chapter to reflect the vibrancy of contemporary research in that area. We have codified the contributions to this edited collection under the two broad themes of (1) natural risks, cosmic hazards and (2) human risks and societal challenges. In this section, we will highlight the key contributions and contents of each chapter within each theme.

1.4.1 Natural Risks and Cosmic Hazards

The start of the discussion on hazards emanating from the cosmic environment begins by considering the risk from asteroids and comets.

It is this risk with which humanity arguably has the longest and deepest association, at least on a cultural level. There is now a widespread public awareness of this hazard, perhaps due to the "impact" in the popular consciousness of the global mass extinction event that led to the demise of the dinosaurs 65 million years ago. More recently, a notable historical impact event occurred at Tunguska, Siberia, on June 30, 1908, in which the explosion of a ~100-meter-sized asteroid or cometary nucleus flattened some 2000 square kilometers of remote forest. The event is often cited as the benchmark for an impact with the capability to destroy a large metropolitan area, and is marked annually by the *Asteroid Day* global awareness campaign.* The threat was vividly demonstrated as recently as 2013 in the Russian city of Chelyabinsk, when the explosive atmospheric disintegration of a ~20-meter asteroid caused extensive property damage and personal injury, mainly due to flying glass shattered by the blast wave.

The spectacular appearance of bright comets has transfixed societies for millennia; our forebears considered them as harbingers of doom. The creation of artifacts from ancient and prehistoric civilizations, including some rock art and megalithic monuments, have been directly linked to episodes of elevated cometary activity (see e.g., Sweatman and Tsikritsis 2017), suggesting—as we have only recently begun to appreciate from astrophysical studies—that activity within the Solar System can evolve on relatively short timescales (see e.g., Napier 2010).

In Chapter 2, Mark Bailey provides a contemporary analysis of the astronomical understanding of the asteroid and cometary populations of the Solar System and the impact hazard they pose. He traces the growth in our knowledge of these *Near-Earth Objects* (NEOs), including basic observational properties such as their size distribution, alongside astrophysical theories for their origin. He explores the history of bombardment of the Earth, the effects of impacts by bodies of different sizes, and the risk they pose at present. By analogy with other low-frequency/high-impact geohazards such as tsunamis, volcanic eruptions, earthquakes, or large-scale floods he presents an insurance-based or actuarial approach to evaluating the average annual cost of NEO impacts and possible mitigation strategies.

Continuing with a Solar System focus, the second contribution on the theme of natural cosmic hazards considers the role of the Sun and its space weather impacts. Just as our ancestors may have observed

* https://asteroidday.org/.

disintegrating comets with a preternatural concern, the northern lights (*aurora borealis* and their southern counterpart the *aurora australis*) may have evoked a similar combination of fear and wonder among populations at high latitudes. For early societies, however, the impact of the typical auroral display was limited to the visual and aesthetic. It was only in the nineteenth century, with the development of electrical technology, that disruptive impacts began to be directly felt and the link with solar activity established. The first such instance occurred during the geomagnetic storm of early September 1859, when intercontinental telegraphy services were subject to anomalous behavior and disruption due to induced currents. The accompanying solar storm, dubbed the "Carrington Event" after Richard Carrington who recorded it (Carrington 1859), remains one of the strongest on record and continues to serve as the benchmark for space weather risk assessments.

With the dependence on electrical and electronic technologies in modern society, our vulnerability to space weather is now much higher. There are a wide range of potential impacts to technological infrastructure on the ground and in space, including, most notably, power grids, navigation, and communication systems. In Chapter 3, Mike Hapgood explains how we can track and forecast the impact of space weather and improve societal resilience to its worst effects. Such is the extent of the potential vulnerabilities that the issue has risen up the policy agenda and is now incorporated in the UK National Risk Assessment, alongside other natural and man-made disaster scenarios. As Hapgood concludes, planning for its effects must also feature in the development of new technologies, such as driverless cars, where the impact on digital devices and navigation systems could have lethal consequences if suitable safeguards and mitigation approaches are not in place.

Chapter 4 completes our coverage of natural cosmic hazards by casting the net beyond the confines of the Solar System and out into the Milky Way Galaxy and the Universe beyond. While Galactic hazards such as gamma-ray bursts, supernovae, and accreting black holes subjectively pose an entirely negligible risk to contemporary human civilization, at least in the sense that the probability of a dangerous event is extremely low on human timescales, they may have impacted the terrestrial environment over the course of the billions of years of Earth's history and have the potential to do so over the next billion years while the Sun permits the Earth to remain habitable. Astrophysicists Richard Wilman, Pratika Dayal, and Martin Ward review the science underlying the "threat" posed by these and other

Galactic hazards, and assess how they may have shaped the habitability of life-bearing planets in our Galaxy and beyond on cosmological timescales. With the explosion in recent decades in the number of known planets around other stars (so-called "exoplanets"), and the prospect that some may harbor soon-to-be-detectable life, they also touch upon some arguably more urgent and certainly more controversial risks surrounding our interaction with any extraterrestrial intelligence.

Their discussion invites a wider philosophical inquiry into the potential range of responses to the discovery of any signals from intelligent life elsewhere in the Galaxy. There is also a question as to the wisdom or otherwise of proactively sending targeted messages to other potentially life-bearing exoplanet systems. Aside from the great technical and sociological challenges associated with these tasks, they bring to light a number of societal considerations. With continuing rapid advances in the study of exoplanets such tensions may become more acute, especially if and when the first signs of life are discovered in exoplanet atmospheres, perhaps within the next decade.

In Chapter 5, we continue to explore the risks posed by physical hazards but move our attention away from those of the natural variety to consider those stemming from man-made space activity in Earth orbit. Camilla Colombo and collaborators examine the risks posed by space debris, both in orbit and on the ground. Earth orbit is littered by a growing population of space debris, deriving from the breakup of operational or defunct satellites and launch vehicles, a problem which will only be exacerbated by current trends in satellite miniaturization (specifically with the development of Cubesats and other smaller satellite platforms) and the proliferation of commercial launch providers.

Their discussion begins with an overview of the current debris population and its long-term evolution, before presenting an evaluation of the in-orbit collision risk and a detailed exposition of the techniques used to evaluate the threat to human populations and infrastructure on the Earth's surface from debris re-entering the atmosphere. Thereafter, they review the technical aspects of the various international measures and guidelines established to mitigate the space debris problem. This includes evaluation of collision avoidance and protection measures and mechanisms for Post Mission Disposal. The chapter ends with an illustrative discussion of so-called "passive end-of-life disposal" methods, which exploit natural orbital perturbations or solar radiation pressure and atmospheric drag.

1.4.2 Human Risks and Societal Challenges

The second part of the book shifts the focus away from risks and hazards which occur naturally or can be understood by scientific analysis. Instead, there is an examination of the way in which human interaction with the space environment has led to a series of risks all of which could have serious implications for human life on Earth. This section develops the problems of managing human-created debris, the threat from terrorism, the ever-present role of the military, and then finally considers the challenges to the Earth posed by a nascent space mining industry. Such considerations will be centered principally, although not exclusively, around the legal and policy-based solutions.

Although this part of the book will look at the overarching governance framework rather than focusing on the minutiae of space law,[*] there will be considerable discussion of the international law framework governing space activity. The Outer Space Treaty 1967[†] (OST) is the most significant element of international space law and is a treaty that was signed before humans had landed on the Moon. The legal framework surrounding the international governance of space has its roots, therefore, in the Cold War. As Gabrynowicz (2004) and Blount (2012) both identify, the primary purpose behind the drafting of the OST was to ensure security for the two cold war power blocs. It has been subject to significant criticism, including observations made within this book, about its relevance and suitability for the modern, multisectored space environment. Despite these criticisms, it remains the first port of call for any inquiry into the legality of space activity (see, for further discussion Lyall and Larsen 2009).

Initially, however, we start with an investigation of how resilience against the effects of space debris, space weather, and other stresses of operating in the space environment has been incorporated into the design and manufacture of satellites over many decades. In Chapter 6, space technology consultant Mark Williamson first explores the technical, or engineering approach, to the mitigation of such risks. Thereafter, he discusses how they can be mitigated financially, in the form of space insurance. In so doing, he

[*] There are a considerable number of "soft law" agreements and guidelines, which comprise the wider governance framework for space activities. See Chinkin (2000) and Goh (2008) for details.

[†] Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies: 610 UNTS 205; 1968 UKTS 10, Cmnd. 3519; 18 UST 2410, TIAS 6347; (1967) 6 ILM 386; (1967) 61 AJIL 644. It was adopted by the General Assembly of the United Nations on December 19, 1966 and opened for signature on January 27, 1967 in London. It entered force on October 10, 1967.

draws on more than 30 years of his own personal experience in technical consultancy to space insurance brokers. He covers the history of the industry—dating back over 50 years, almost to the dawn of the Space Age—the nature of the market and its capacity, the types of coverage available, and the process of arranging cover and calculating premium rates and losses. He concludes with a look to the future of the industry, arguing that the demand for such cover will likely only increase as developments such as commercial space tourism and resource exploitation reach fruition.

In Chapter 7, Christopher Johnson of the Secure World Foundation revisits the question of human-made space debris and in doing so, links the technical coverage of the first theme with the law and policy analysis of the societal challenges. He explores notions of "Space Sustainability" in Earth orbit and considers what action needs to be taken to ensure that the space environment remains capable of meeting the needs of the present day and those of future generations. This discussion encompasses the space debris problem, complementing the technical coverage of Chapter 5 discussing the issue of nonbinding, debris mitigation guidelines (for further details see Hobe and Mey 2009). There is also consideration of potential problems such as radio frequency interference and concerns that beneficial space technology may not reach fruition due to political considerations which jeopardize its development. In doing this he studies emerging tensions in the Outer Space Treaty and their implications for the development of planetary defense mechanisms, resource exploitation, and the possibility of conflict in space.

Whereas the focus of the book to this point has been on unintended risks, it now shifts in Chapter 8 to intentional threats designed to cause significant disruption to space activity and the infrastructure on Earth. Ben Middleton brings his expertise as a researcher in terrorism to explore the risks posed to space activity from terrorism. The discussion identifies terrorism as a quintessentially human phenomenon and warns that the risk of terrorist activity expanding out into space must not be ignored. Middleton identifies that the most serious short-term threat comes from targeted activity against satellites and describes a number of scenarios where state and private terrorist actors could cause serious damage and disruption to the space infrastructure. The chapter ends with a call for bespoke policies and capital expenditure to protect vital space assets from being targeted by rogue states and terrorist groups.

Acknowledging that terrorist activity in space is likely to emanate from rogue states provides a useful segue into the next element of discussion of the risks in space from human activity. In Chapter 9, space attorney and founder and principal of Space Law and Policy Solutions, Michael Listner, illustrates the way in which human space activity has, largely, been the product of military activity. In a provocative and challenging discussion he maintains that in spite of the peaceful rhetoric embraced by academic commentators and various international institutions, most notably the United Nations, the attractiveness of space-based military assets and the development of advanced weaponry means that space remains a key theatre of military activity.

Listner argues that the current legal architecture for the governance of space activity is archaic and needs to evolve to more effectively manage the challenges and risks posed by military activity. This discussion provides an important counterpoint to the other contributions on policy and law. It reflects the realpolitik of modern geopolitics and illustrates the crossroads at which space governance finds itself. The certainties of the cold war and the consensus regarding the way in which space should be governed and developed have been eroded. The Outer Space Treaty and its cadre of related treaties still form the bedrock of normative behavior in space, yet the risk of instability and conflict is a genuine concern should this international consensus break down.

It is apposite that a significant risk to the international consensus is identified in the final chapter. Space law academics Thomas Cheney and Christopher Newman examine the way in which the nascent space mining industry could threaten the fabric of the international cooperation, which has underpinned space governance since the start of human activity. This chapter outlines that the current legal framework prohibits the appropriation of the Moon and other celestial bodies. A strict reading of Article II of the Outer Space Treaty would seem to suggest that states or private companies would not be able to lawfully possess any minerals mined from celestial bodies and even the very act of mining them could fall foul of international space law.

The lack of a compliant framework for the mining and trading of space resources risks the stability of the international governance framework underpinning human space activity. While the technological infrastructure of future mining ventures is at present unclear there is sufficient interest from private sector companies (particularly in the United States) to indicate that the legal problems of ownership will need to be addressed sooner rather than later. Both the United States and Luxembourg have already acted unilaterally to recognize mining as an aspect of the usage of space (as permitted under

Article I of the 1967 Treaty) rather than an attempt to "own" the celestial body. Cheney and Newman navigate through contemporary academic debate on this area and pose solutions based on a pragmatic adaption of existing international law. It is suggested that, given current geopolitical conditions, a new overarching space governance treaty is unlikely. The chapter finishes on an optimistic note, however, suggesting that the best way to ameliorate the risks from increased competition in space is by building on currently accepted norms and developing consensus on this area.

1.5 CONCLUSIONS AND OPPORTUNITIES

The scope and intensity of risks outlined in this book range from potential extinction events through to disruption of the current geopolitical governance arrangements for space activity (which may indeed be welcomed by some). The probability of these risks occurring also varies wildly—from the statistically insignificant through to the highly likely. What all of these risks have in common, however, is that they all occur in areas that would benefit from further academic study. While humanity may not currently be able to prevent the impacts of many of the natural cosmic hazards, this is not an immutable state of affairs and there is a clear advantage in achieving a deeper understanding of them.

The risks to Earth from human space activity may well have a higher probability of occurrence; while they are unlikely to result in the extinction of our species, they could have a significant impact upon our society. The "Kessler Syndrome" poses a clear risk to our ability to remain a spacefaring civilization and that threatens all space-based applications, communications, and GPS. The risk to life from terrorism or military activity and political instability may appear mundane in contrast to the natural cosmic hazards but their impact is no less worrying. Again, innovative legal and policy solutions are required to ameliorate the dangers from such risks. Going forward, it is suggested that we need clear and thoughtful leadership to ensure the implementation of broadly accepted governance frameworks.

As stated earlier on, it was a conscious decision not to assess the risks to humans *in space*. There has been some significant work already undertaken on this, such as Harrison (2001) on the risks to humans should we engage in long distance spaceflight and the work of Butler (2006) and Robinson (2006) on the issues facing human settlers on other worlds with respect to planetary contamination. These are all areas worthy of further study in a more suitable project and would undoubtedly enhance the understanding and appreciation of the risks to humans as space activity continues to develop.

A further, and wholly cognate, area of study that would draw on discussions which have been started by others, such as Dick (2015), center around the risk to humans from the discovery of extra-terrestrial life. The philosophical and cultural implications alone present a risk to the current fabric of society and there are significant questions which could be addressed in the context of both naturally occurring hazards from the discovery of life and the associated societal challenges.

Fundamentally, it is hoped that this book will stimulate a critical and enduring discourse concerning the nature of the risks posed by the space environment and the response to the societal challenges. This will allow policy makers, governments, and those with institutional responsibility to foster a clear and proportionate approach to the allocation of resources appropriate for managing these risks.

Perhaps the single most important contribution this book can make is by illustrating the utility of a truly cross-disciplinary approach to the study of space risks. Only by collaborating outside of the usual silos of activity will truly enduring solutions to managing the risks posed from the frontier of space be found. If this book in some way contributes to this process, then we will have realized our ambitions for the project.

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CHAPTER 2

Asteroid and Cometary Impact Hazards

Mark E. Bailey

CONTENTS

2.1 INTRODUCTION

For the first time in the c.4000 million-year history of life on Earth, a species—namely we human beings—has developed, which broadly understands Earth's place in space and the key factors that drive the development and evolution of life on Earth. Within just the last 50 years, humanity has come to realize that, contrary to the image popularized by Sagan's "Pale Blue Dot," the Earth does not hang isolated in space lit by a constantly shining Sun, but rather is a dynamic system interacting with and open to a constantly changing near-Earth celestial environment, and illuminated by a time-variable Sun. If extraterrestrial effects were tiny, we could be forgiven for ignoring them; but they are not. Rare impacts on the Earth by asteroids and comets, comprising the larger elements of the so-called Near-Earth Object (NEO) population, have driven major changes in the evolution of life on Earth over geological timescales and are key to the long-term future of the human race. Having recognized this risk, humans living in the twenty-first century are now faced with a unique responsibility to understand the risks and opportunities posed by Earth's near-space celestial environment and to respond appropriately. This chapter provides an overview of the hazards, as currently understood, posed by asteroids and comets in the Solar System.

2.2 BROAD VIEW

We are living through a unique period in Earth's history. From the earliest beginnings of life on Earth, less than a few hundred million years after the late heavy bombardment some 4000 million years ago, life has had a continuous toehold on Earth. For the first nearly 3000 million years of this enormous timescale, life's self-replicating organisms were fundamentally microscopic in scale and it was not until approximately 700–600 million years ago, leading up to the Cambrian Period (around 541 million years ago) and the beginning of the Phanerozoic Eon, that we begin to see abundant evidence for macroscopic fossil life. The fossil record presents us with an almost unimaginable range of different types of organisms, all of which appear destined ultimately to become extinct after timescales ranging from less than a million years to typically ten million years, or in some cases as long as several hundred million years; but in all cases on a timescale much less than the age of the Earth.

The story of the development of *intelligent* life on Earth is no less remarkable. Whereas most people would agree, to take a trivial example, that cats and dogs, or porpoises and whales, show evidence of intelligence in the way they interact with the world around them, it is not yet widely accepted that these kinds of creatures are self-aware—though to a lesser extent—in qualitatively the same way as humans.

Humanity, of course, is a proud species, with many members still inclined to see themselves as separate from others in the animal kingdom despite recognizing that humans are part of the evolutionary tree. Nevertheless, human beings do occupy a special place at the top of the tree when it comes to intelligence and in their ability to operate effectively in widely differing environments, as well as their power to affect the inanimate world around them including the terrestrial life forms with which they come into contact. Despite this advantage, there is no strong reason to believe that humanity will necessarily last longer than (say) the most highly successful groups in the fossil record, or that a new better adapted and even more capable entity might not one day evolve to replace it.

Apart from their innate intelligence and adaptability, humans have also—and this is a very recent development—learned much about planet Earth and its place in the cosmos. Within just the last few hundred years our collective astronomical knowledge has grown enormously: to encompass a coherent understanding of the first seconds of the entire 14 billion-year-old expanding Universe; the origin of the chemical elements of which we are all made; Earth's place in space; our Solar System's place in the Galaxy; and our Galaxy's place in the Universe. There are hundreds of billions of galaxies in the known Universe, each with tens or hundreds of billions of stars, of which many—perhaps the majority—will have planetary systems that might provide opportunities to possibly host exotic self-replicating organisms.

In the light of this broad understanding it seems inescapable that our Galaxy must be teeming with life. Some of these extraterrestrial life forms will be intelligent, as on Earth, and—like humans—possibly have the ability to recognize their place in space. Whether, like humans, they remain "Earth bound" or instead have grasped the opportunities of interplanetary and interstellar travel is currently unknown. However, because there is still no proof that extraterrestrials have yet visited Earth the average lifetime of technologically capable civilizations must be very short, or perhaps such species may prefer to stay at home; or possibly the undoubted difficulties of interstellar travel have proved insurmountable. Alternatively, perhaps we should get used to the idea that the development of a technologically adept species with the ability to leave its home planet is an extraordinarily rare occurrence in the evolution of life, and human beings are not just unique but possibly alone in the Galaxy?

Either way, we are inexorably drawn to conclude that life on Earth is precious. With humanity's growing understanding of the fragility of the various habitable zones of our planet, and their frailty on the cosmic stage, it behooves us to protect and preserve where possible the only place in the Universe where we are certain that intelligent life can exist.

In short, twenty-first-century humans—the first life-forms on Earth with the knowledge and power to act with space awareness—find