Handbook of Cosmic Hazards and Planetary Defense
DOI 10.1007/978-3-319-02847-7_85-1

Introduction to the Handbook of Cosmic Hazards and Planetary Defense

Joseph N. Pelton[a]* and Firooz Allahdadi[b]
[a]Executive Board, International Association for the Advancement of Space Safety (IAASS) and Director Emeritus, Space & Advanced Communications Research Institute (SACRI), George Washington University, Arlington, VA, USA
[b]Space Science & Environmental Research, ARA Corporation, Albuquerque, NM, USA

Abstract

Each year humans travel through space on their own very special spacecraft called planet Earth, but that trip around the Sun is actually a very hazardous journey. Without the benefit of a space program, the human species has spent millions of years unaware of the wide range of cosmic dangers that lurk out in space. In some ways humans are playing Russian Roulette with a random set of rock and metal bullets that were first fired at this small six sextillion ton planet millions if not billions of years ago. These bullets are potentially hazardous asteroids, bolides, and meteorites. In addition there are comets that streak down toward the Sun from the Oort Cloud every few years. Perhaps an even greater danger to humans come from the nearby nuclear furnace called the Sun. Solar flares, coronal mass ejections, and continuous radiation from the Sun are warded off by the Van Allen Belts, the Earth's geomagnetosphere, and the ozone layer that sits atop the stratosphere. During the height of the Sun's activity that follows an 11-year cycle, the radiation and solar eruptions from the Sun hit very dangerous levels. Current research that examines the Van Allen Belts and the Earth's magnetic shielding suggests that the protective magnetosphere shielding that protects life could be changing. And then there are other hazards from space. These risks include increasing levels of orbital debris and returning spacecraft that may contain nuclear, radiological, or chemical dangers, or even biological dangers.

The *Handbook of Cosmic Hazards and Planetary Defense* seeks to examine in depth the various dangers that the delicate Earth Habitat could be exposed to from outer space risks and what research needs to be done to understand in greater depth the nature of these dangers. And the editors and the authors of this book are defining "cosmic hazards" in the broadest possible terms. Thus, these hazards from outer space include comets, asteroids, and bolides that might collide with Earth. The risks to humans and modern global infrastructure include solar flares, coronal mass ejections, solar proton events, and other space weather events, as well as changes to the Earth's protective shielding from cosmic hazards such as a lessened magnetosphere, altered Van Allen Belts, and a depleted ozone layer. This chapter also addresses orbital debris (in terms of its impact on Earth and aircraft as well as such debris possibly endangering vital infrastructure and satellite networks). This chapter even considers such hazards as cosmic radiation, antimatter events, and lethal biological agents that could come to Earth in various forms, including via returning spacecraft or astronauts.

The last part of the chapter builds on what is known about the dangers of outer space and presents the various types of activities that humans are beginning to undertake to protect life on Earth. This latter part of the handbook sets forth what types of activities can serve to protect humans and indeed all types of life-forms from mass extinctions. Such massive loss of species that include a third or more of all types of life-forms has been documented to have occurred at least five times during the

*Email: joepelton@verizon.net

DOI 10.1007/978-3-319-02847-7_85-1

Earth's existence. These past mass extinction events have come about, on average, every 300 million years or so, over the last two billion years. These massive losses of life serve as powerful reminder that not only are there powerful hazards that can wipe out life on a massive scale, but that unless protective measures are undertaken, they could happen again with devastating effect. The rise of mass urbanization that may exceed 70 % of all people living in towns of cities by 2,100 coupled with the enormous dependence on modern infrastructure such as electric power grids, telecommunications and information systems, and vast utility plants make twenty-first-century vulnerabilities to cosmic risks far greater than any previous time in human history.

The objective of this chapter is thus to present in detail what is known about the hazards of outer space and the scientific and technical nature of these threats. Further this handbook seeks to identify but what steps can be undertaken to initiate a creditable planetary defense effort. It is such an effort that can unite all the people of planet Earth in a great and common undertaking.

Keywords

Advanced Composition Explorer (ACE); Antimatter; Bolides; Biological and radiological contamination from space; Carrington event; COPUOS; Coronal mass ejections; Earth guard; ESA; Gamma rays; Geomagnetosphere; Mass extinctions; Millennium ecosystem assessment; Near-Earth objects; NASA; NEOWISE; Orbital debris; Palermo scale; Potentially hazardous asteroids; Sentinel infrared space telescope; Solar and Heliospheric Observatory (SOHO); Solar flares; Solar max/solar minimum; Sustainability of space; Space weather; Torino impact hazard scale; UNISPACE; United Nations; Van Allen Belts; Van Allen storm probe; Wide-Field Infrared Survey Explorer (WISE); X-Rays

Introduction

The threats that come from outer space are both frightening and numerous in types and nature. The Earth and its various life-forms – both animal and plants – are only protected by a thin atmosphere and a magnetosphere subject to change and weakening over time. There are powerful eruptions from the Sun and a large number of potentially deadly asteroids that only in the last 50 years have become systematically detectable by scientific satellites. Likewise it is only recently that scientific investigation has revealed the true nature and magnitude of mass extinction events where a significant number of species living on planet Earth were wiped out. Today the extent of dangers to human survival and the scope of risks to modern ways of life that come from outer space are much more clearly understood than ever before. And these dangers come from many different sources that include near-Earth objects, potentially hazardous asteroids and comets, solar flares, coronal mass ejections, solar proton events, cosmic radiation as well as solar weather events and even more exotic concerns such as matter-antimatter collisions.

And human activities involving space exploration and applications can also lead to threats and dangers. These include orbital debris that can threaten vital space infrastructure like communications satellites, meteorological spacecraft, and positioning navigation and timing satellites. There is even risk from reentering spacecraft that can bring back chemical, radiological, nuclear, or even biological threats. As orbital debris mounts and more and more satellites deorbit, this could bring physical danger to aircraft or people and facilities on the ground. Today exponential population growth and human industrial activity that generates greenhouse gases when interacting with the Sun's energy

Handbook of Cosmic Hazards and Planetary Defense
DOI 10.1007/978-3-319-02847-7_85-1

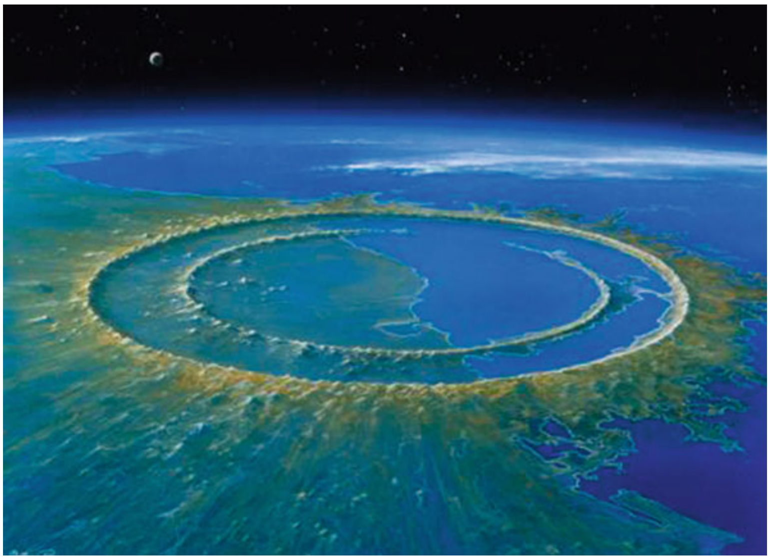


Fig. 1 The 180 km across meteor crater on the Yucatan plateau (Graphic Courtesy of NASA)

can lead to climate change and global warming that could lead to life-annihilating results such as the runaway heating that occurred years ago on the planet Venus. Even this is a form of risk from the cosmos, but because so much is being written on this subject and is a matter of such broad concern, it is not explicitly addressed in this handbook.

This handbook thus defines "cosmic hazards" broadly. The purpose of this book is to explore all of these dangers that come from outer space and shares as much technical and scientific knowledge as is now known about these "space threats." It continues on to explore what actions might be undertaken to prevent or mitigate these space threats in terms of a concerted effort to undertake a planetary defense against these dangers. This introductory chapter seeks to provide an overview of the various elements addressed in the totality of the handbook to provide a synoptic context as to the nature of the threats and how space research and ground-based observations are constantly seeking to learn about these various potential threats and to begin charting a course forward toward a systematic and hopefully effective planetary defense of life on Earth.

The Threat from Near-Earth Objects

In the last few decades, scientists have discovered more and more evidence of the various types of cosmic hazards that lurk out in space. In 1980s a huge circular crater was discovered that is 180 km across and 900 m deep. This huge and perfectly shaped circular crater ranges along the coast of Mexico's Yucatan plateau and extends well out into the Gulf. By the 1990s space imaging was able to confirm that this was indeed the remnant of the giant asteroid that smashed into Earth. This event, which was the equivalent to the explosion of tens of thousands of nuclear bombs blocked out the Sun with the cloud of dust that ensued. This was an event termed "Nuclear Winter" during the Cold War era. This mass extinction event (known as the K-T event) not only killed off the dinosaurs some 65 million years ago but it also extinguished about two thirds of all plant and animal species that were alive on the day of this devastating impact. This was Earth' Big Bang. The ultimate verification that this was the remnant of a huge meteor collision proved that not only could potentially hazardous

DOI 10.1007/978-3-319-02847-7_85-1

asteroids could hit Earth but do so in a way that can wipe out human civilization as it is known today (Dinosaur Killer 2003) (Fig. 1).

The more recent wake-up call about space hazards that can crash into planets at supersonic speeds came in 1994. This was when astronomers were able to train their telescopes on Jupiter and watch the impact of a multi-part comet as it crashed at tremendous velocity into the Solar System's largest planet. This all occurred some 20 years ago when the Comet P/Shoemaker-Levy 9 (note that its formal designation is D/1993 F2) collided with Jupiter. This comet that was first witnessed on March 24, 1993, by Carolyn and Eugene Shoemaker and David Levy at the Palomar Observatory in California had, of course, been predicted well before this catastrophic event actually occurred. There were actually twenty-one discernible parts to the comet "complex" – with some parts being as large as 2 km in diameter (Comet Shoemaker-Levy Collision with Jupiter 1994).

During a 6-day period from 16 to 22 July 1994, pieces of the comet bombarded Jupiter with explosive force that could easily be seen through telescopes. This was the first such collision of two Solar System bodies ever to be observed and recorded, and the impact on Jupiter and its atmosphere were truly spectacular. A previous encounter with Jupiter's gravitational field in 1992 had actually pulled the comet apart to form the 21 pieces. The observed speed of collision was at 216,000 km/h or at134,000 miles/h. The huge scars from the impact left on the surface of Jupiter were larger than the Great Red Spot and remained apparent for many months. Since the size of the Great Red Spot is more than ten times the entire cross section of the Earth, one can only imagine the destructive power of this six day galactic bombardment (Comet Shoemaker-Levy Collision with Jupiter 1994).

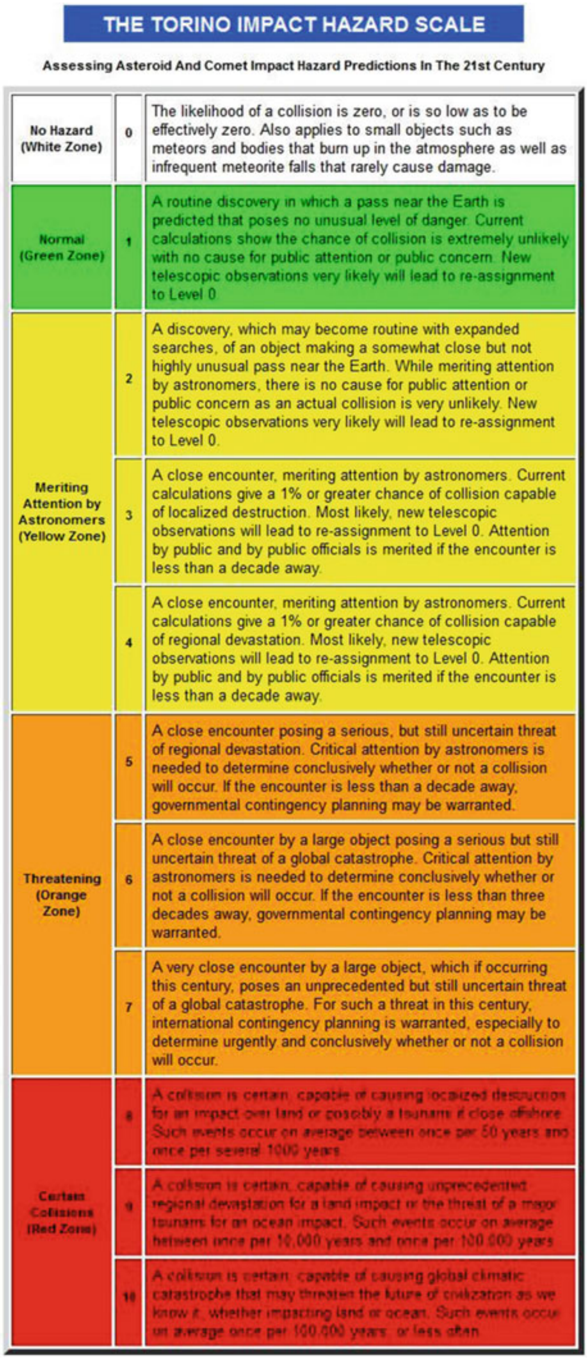
It is completely plausible that if this 21 piece avalanche of space rocks had hit Earth, human life as it is known with all its modern life and societal infrastructure would have been completely wiped out along with vast numbers of plants and animals.

The fact that Comet P/Shoemaker-Levy 9 impacted Jupiter rather than Earth is not at all unusual because comets and asteroids hitting Jupiter are calculated to be at least 2000 times more likely because of Jupiter's huge cross section and its tremendously strong gravitational field. In short Jupiter's enormous gravity well along with the Sun actually serves as a sort of "cosmic vacuum sweeper" to attract dangerous space rocks to crash into this giant planet or the solar furnace rather than Earth. Saturn and Uranus to an extent help as well, but Jupiter serves a particularly vital function in protecting Earth from comets and potentially hazardous asteroids. For those who say that such threats can be forgotten since they are millions of years away, they need to focus on the destructive force of the Shoemaker-Levy comet that would have destroyed human civilization and that this event occurred only two decades ago.

Scientists have tried to come to terms with the types of threats that near-Earth objects of various kinds that exist out there and to try to put these dangers into some form of perspective. The result was the so-called Torino Scale that was formally adopted by the scientists that attended the Unispace II Conference in Vienna, Austria. The concept of the Torino Impact Hazard Scale was to create a system analogous to the Richter Scale for Earthquakes. The problem is that the general public has difficulty dealing with very small probabilities combined with hugely disastrous consequences. Tell them they have a 1 % chance of surviving an operation and this makes some sense. Tell them that within a range of 50 years to over a 1000 years, there is a very serious chance of a big space rock doing very serious damage to global society, and they are perplexed but have no clue what to do about it. If it is not immanent, the public tends to say let's move on to today's crisis. When the Shoemaker-Levy comet was smashing into Jupiter, the Jet Propulsion Labs web site on this topic had millions of hits in 1994, but today the event is all but forgotten (Fig. 2).

The Torino Scale helps us assess the enormity of a threatening collision by a near-Earth object. There is also something called the Palermo Scale that provides a useful assessment of the likelihood

Handbook of Cosmic Hazards and Planetary Defense
DOI 10.1007/978-3-319-02847-7_85-1



THE TORINO IMPACT HAZARD SCALE

Assessing Asteroid And Comet Impact Hazard Predictions In The 21st Century

No Hazard (White Zone)	0	The likelihood of a collision is zero, or is so low as to be effectively zero. Also applies to small objects such as meteors and bodies that burn up in the atmosphere as well as infrequent meteorite falls that rarely cause damage.
Normal (Green Zone)	1	A routine discovery in which a pass near the Earth is predicted that poses no unusual level of danger. Current calculations show the chance of collision is extremely unlikely with no cause for public attention or public concern. New telescopic observations very likely will lead to re-assignment to Level 0.
Meriting Attention by Astronomers (Yellow Zone)	2	A discovery, which may become routine with expanded searches, of an object making a somewhat close but not highly unusual pass near the Earth. While meriting attention by astronomers, there is no cause for public attention or public concern as an actual collision is very unlikely. New telescopic observations very likely will lead to re-assignment to Level 0.
	3	A close encounter, meriting attention by astronomers. Current calculations give a 1% or greater chance of collision capable of localized destruction. Most likely, new telescopic observations will lead to re-assignment to Level 0. Attention by public and by public officials is merited if the encounter is less than a decade away.
	4	A close encounter, meriting attention by astronomers. Current calculations give a 1% or greater chance of collision capable of regional devastation. Most likely, new telescopic observations will lead to re-assignment to Level 0. Attention by public and by public officials is merited if the encounter is less than a decade away.
Threatening (Orange Zone)	5	A close encounter posing a serious, but still uncertain threat of regional devastation. Critical attention by astronomers is needed to determine conclusively whether or not a collision will occur. If the encounter is less than a decade away, governmental contingency planning may be warranted.
	6	A close encounter by a large object posing a serious but still uncertain threat of a global catastrophe. Critical attention by astronomers is needed to determine conclusively whether or not a collision will occur. If the encounter is less than three decades away, governmental contingency planning may be warranted.
	7	A very close encounter by a large object, which if occurring this century, poses an unprecedented but still uncertain threat of a global catastrophe. For such a threat in this century, international contingency planning is warranted, especially to determine urgently and conclusively whether or not a collision will occur.
Certain Collisions (Red Zone)	8	A collision is certain, capable of causing localized destruction for an impact over land or possibly a tsunami if close offshore. Such events occur on average between once per 50 years and once per several 1000 years.
	9	A collision is certain, capable of causing unprecedented regional devastation for a land impact or the threat of a major tsunami for an ocean impact. Such events occur on average between once per 10,000 years and once per 100,000 years.
	10	A collision is certain, capable of causing global climatic catastrophe that may threaten the future of civilization as we know it, whether impacting land or ocean. Such events occur on average once per 100,000 years, or less often.

Fig. 2 Torino impact scale for potentially hazardous asteroid (Graphic Courtesy of the UN Unispace Conference) http://neo.jpl.nasa.gov/torino_scale.html

that a rogue space object will actually collide with Earth. NASA maintains a so-called Sentry Risk Table that monitors all known near-Earth objects and assigns to those that could come into conjunction with Earth a Palermo Scale number. Near-Earth object 2007 VK384, for instance, will swing by Earth in 2048 and has a Palermo scale number of −1.57 which means a very low probability (NASA Sentry Risk Assessment).

The problem is that the needed inventory of the skies is far from complete. But fortunately scientists and engineers are developing improved infrared space telescopes that when combined

Handbook of Cosmic Hazards and Planetary Defense
DOI 10.1007/978-3-319-02847-7_85-1

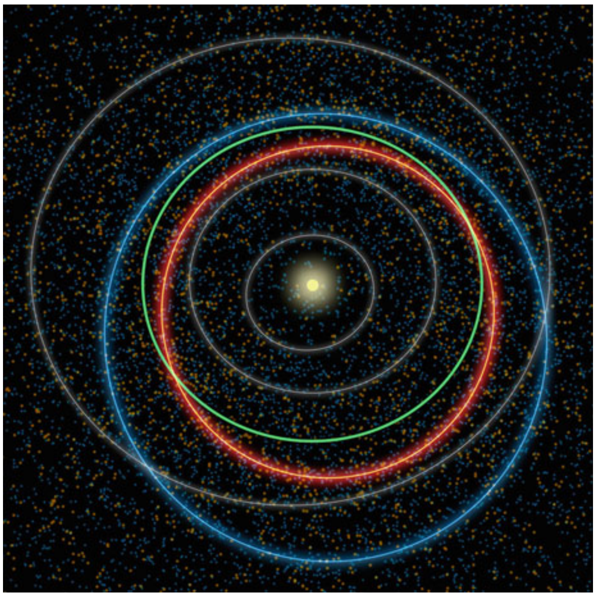


Fig. 3 Charting the orbits of potentially hazardous asteroids (Graphic Courtesy of NASA)

with Earth observatories, can help us better map the heavens to discover possible threats to Earth with the hope that a major threat could be averted before it could destroy human civilization. The Wide-Field Infrared Survey Explorer (WISE) has helped identify an estimated 80 % of all potentially hazardous asteroids that are greater than 1 km in size that might possibly collide with Earth (WISE: The Wide-field Infrared Survey Explorer). Unfortunately a near-Earth object that is just 30–40 m in size can be a "city killer," and only a small fraction of these smaller potentially hazardous asteroids have been identified.

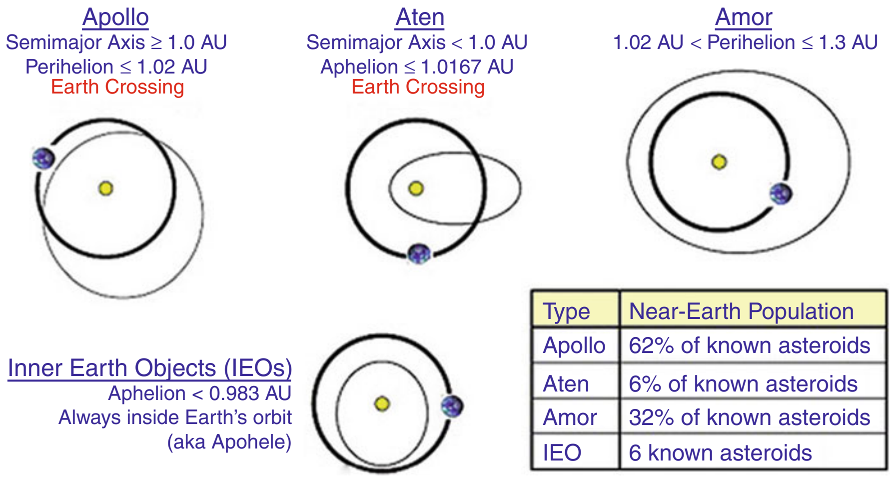
Despite the fact Jupiter "vacuums" up many potentially hazardous asteroids, there are a surprising number of space rocks out there that could still do us a great deal of harm. The following graphic shows in blue the orbital characteristic of a "typical" near-Earth asteroid and in red is a "typical orbit for a potentially hazardous asteroid (See Fig. 3 below). It is far from reassuring to know that there are tens of thousands of these potentially hazardous space rocks out there circling the Sun in orbits that could intersect with Earth twice each time they go around the Sun.

This "typical" PHA orbit, which relates to asteroids known as the "Apollo" type of near-Earth objects, actually represents about 62 % of the population according to JPL scientists. As can be seen in Fig. 4, there are also asteroids that have larger orbits than that of the Earth and thus are greater than one astronomical unit in size. These types of asteroids could become a problem if their orbits decay over time. These "Amor" asteroids are about 32 % of the population. Then there are the Aten asteroids that have an elliptical orbit that goes near the Sun in their perihelion and then reach an apogee well above the Earth's orbit and can also cut across Earth's orbit twice a year. These represent about 6 % of the population (Jet Propulsion Laboratory background on PHAs).

Different Types of Near-Earth Objects and Their Various Kinds of Orbits

Former Congressman George Brown, who headed the Congressional Science and Technology Committee for many years was memorialized by a US legislation passed in 2005 to assign the

Handbook of Cosmic Hazards and Planetary Defense
DOI 10.1007/978-3-319-02847-7_85-1



Type	Near-Earth Population
Apollo	62% of known asteroids
Aten	6% of known asteroids
Amor	32% of known asteroids
IEO	6 known asteroids

Fig. 4 Different types of orbits for near-Earth objects (Graphic Courtesy of the Jet Propulsion Laboratory)

task to NASA and Earth observatories to chart 90 % of all near-Earth objects (larger than 140 m) by 2020 (Section 321 of the NASA Authorization Act of 2005).

This initiative is sometimes informally known as Spaceguard. And NASA together with other space agencies and ground observatories has been working on this quite hard for well over a decade. The good news is that the paths of about 80 % of the biggest of these rocks that are a kilometer or more in size are now known. The WISE space telescope and especially the NEOWISE program and Earth observation have given us a good deal of good information. This is reassuring. Yet, those near-Earth objects that are under 1 km in diameter are still 90 % unknown despite the efforts that NASA and others have made.

One might be tempted to say: "Probably that is okay because it is the really big space rocks that would really do catastrophic harm." But they would be wrong.

Let us consider something like the space rock known as Apophis, which is only about 300 m in diameter. This particular space rock will whiz by Earth in 2029 and again in 2036. This "small space rock" could do enormous harm. At a speed of 60,000–70,000 km/h, damage from an Apophis-sized rock could be equivalent to thousands of atomic bombs, and at the right location, it could trigger a tsunami that could destroy the Eastern Coast of the USA or Tokyo and Osaka in Japan. When it realizes that over 80 % of the space rocks of this size are still unknown, then any sense of reassurance evaporates away again. NASA has admitted that it cannot achieve the objective of 90 % mapping of all near-Earth objects 140 m in size or larger by 2020 in its formal report to the Congress in 2007. The 2005 Act also required a report to the Congress that analyzed possible options that might be employed to divert a hazardous space rock from colliding with Earth if actual threats were detected. While the NASA report did analyze options, it also indicated that better technology needed to be developed and no single method (with the possible exception of nuclear devices being used) provided a high level of confidence as to a fully effective response.

This lack of progress as reported in 2007 and in the years that have followed is why the B612 Foundation has started its own initiative to launch the Sentinel infrared space telescope to increase a planetary early warning system for life-threatening space rocks. This new initiative that was formally announced on June 28, 2012, will be dedicated to surveying and identifying all near-Earth objects down to 140 m in size and has the potential to identify threats down to 30–40 m in diameter. As currently designed and engineered, this space telescope could even seek to create over time an inventory of virtually all space rocks that could create major damage. This is a $450 million project

Handbook of Cosmic Hazards and Planetary Defense
DOI 10.1007/978-3-319-02847-7_85-1

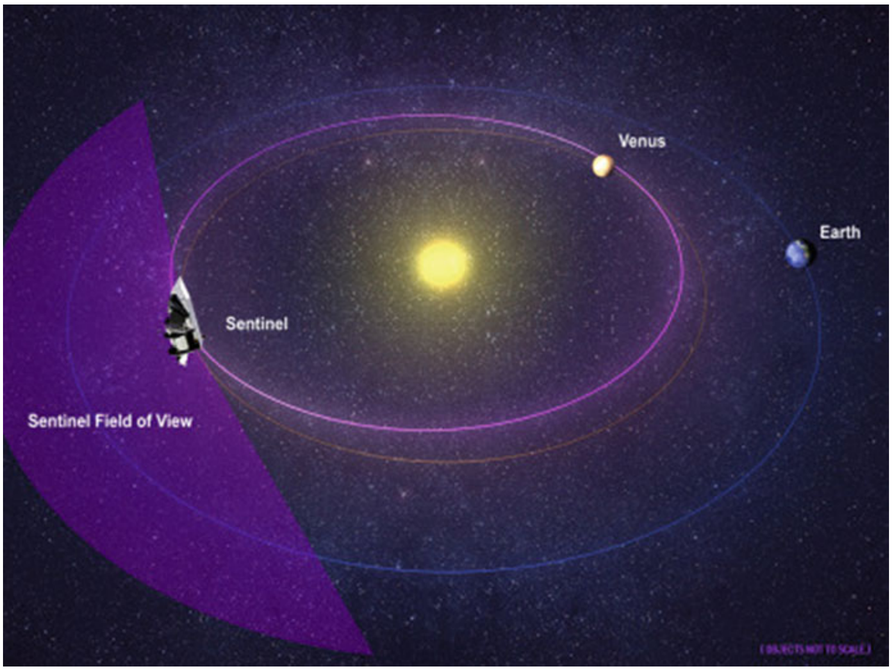


Fig. 5 Representation of sentinel infrared space telescope deployed in space (Courtesy of B612 Foundation – Not to Scale)

that is seeking to build, deploy and operate an infrared space telescope that could provide us consistent and long-range warning of any possible future strikes by a potentially hazardous asteroid that might be lurking out there in space (The B612 Foundation) (Fig. 5).

And unfortunately there is much more to be known than just the presence and the precise orbits of these space rocks – even though this is clearly the place to begin. One needs to know about the composition of these asteroids (i.e., rock, dirt, chemicals, or various metals from light to very heavy) and their shape and their relative velocity with respect to Earth. It is also important to know how the Sun's radiation and gravity can impact these asteroids as well. A smaller asteroid consisting of heavy metals and traveling at a relative velocity of 100,000 km/h might actually do more damage than a larger and "softer" space rock traveling at a slower pace. Here is a calculation based on a 30 m asteroid with a radius of 15 m traveling at 100,000 km/h or 27,500 m/s and based on the assumption that, like Earth, the mass density is six times that of water or about 6,000 kg/m^3.

The amount of power released by the impact would be 7.250 terawatts. If one were to calculate what an asteroid that is at the low end of what the US Congress specified that NASA would use in surveying the heavens for space rocks, i.e., 140 m across, then the calculated power release would be 740 terawatts. And to assess the impact of an asteroid that is 1 km in diameter, the calculated power release would be 260 quadrillion watts. This is 260,000,000,000,000,000 W. This represents enough energy to keep the Earth running for many, many years if converted to electrical energy. The "typical hurricane" power release, which is much greater than a nuclear bomb, is around 50 trillion watts.

Knowledge of the composition is important to know not only in terms of the damage that might be done, but also this is key know in terms of devising a scheme to ward off the impact as well.

There is actually a good deal being done to map the orbits of these space rocks. There are research programs to learn about how the Sun's gravity might create a so-called keyhole effect to change the orbit of a deadly asteroid. These investigations that are seeking information about the Yarkovsky effect are also seeking to learn how the Sun's radiation can alter over time and thus change the orbit of potentially hazardous asteroids as well.

Handbook of Cosmic Hazards and Planetary Defense
DOI 10.1007/978-3-319-02847-7_85-1

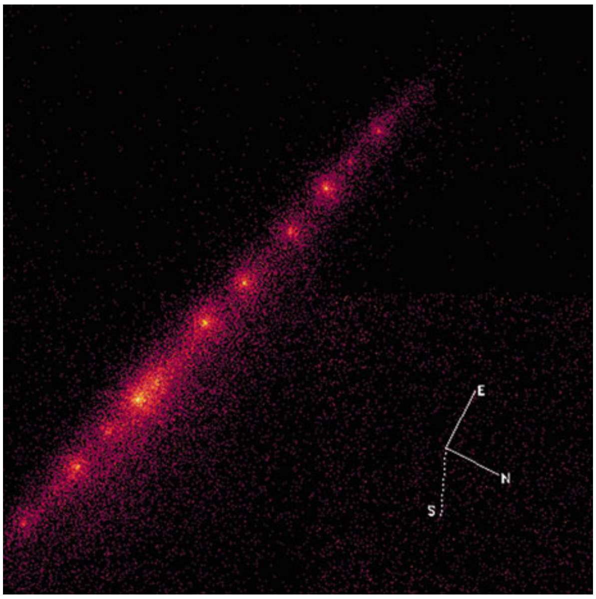


Fig. 6 The so-called String of Pearls Shoemaker-Levy comet streaking in the sky (Graphic Courtesy of NASA from the Hubble Space Telescope)

Activities such as NEOShield (2012) and the Spaceguard Foundation (The Working Group 1995) are now underway to study the best methods to ward off a catastrophic collision with Earth. This is the good news. The more sobering news is that humans are not equipped to deal effectively with a killer asteroid or other potentially hazardous near-Earth object. This is particularly true if it was learned that an asteroid would impact Earth in just a matter of weeks. Fortunately no such fate is immanent.

Comets

The number one concern with regard to near-Earth objects is actually asteroids and bolides. This is simply because of their sheer numbers. There are many thousands of these objects that are large enough to cause catastrophic damage to Earth if they should actually collide. Their high relative velocity and mass make them a very lethal encounter of the most unwelcome kind.

Yet there are other types of space objects that also could come close to Earth that are also worthy of careful study as well. These are the comets that come streaking down from the Oort Cloud region beyond Pluto on a periodic basis and then go zooming back outside of the Solar System. The most famous of these is the Halley's comet, but in terms of understanding the threat that a comet might pose to planet Earth, the so-called Shoemaker-Levy 9 comet has no peer (See Fig. 6).

The Shoemaker-Levy comet (or indeed its multiple elements) that smashed into Jupiter in 1994 with such devastating force demonstrates with an exclamation point that it is important to track and monitor comets as well. This 1994 event was actually helpful to researchers of cosmic hazards in several ways.

It allowed us for the first time to observe and record the effects of comet elements as they smashed into a planet.

It also helped us to understand even more clearly the extent to which Jupiter does act as a protector of Earth by virtue of its huge gravity well. The gravitational effect of this huge planet helps to capture

DOI 10.1007/978-3-319-02847-7_85-1

both near-Earth asteroids, bolides, and comets that might otherwise someday crash into Earth. Although the same could also be said about other elements of the Solar System with gravitational mass, the truth is that the Sun and Jupiter are by far the main line of defense.

Thirdly Jupiter and the Sun could also become logical "ultimate destination targets" if it became possible to develop the technology to divert the orbits of near-Earth objects that are directly threatening Earth – assuming the threat is detected early enough in time. This means that it is the current objective to deploy systems out into space that are capable of changing the path of potentially hazardous asteroids and to redirect them so that they would then be captured by the gravity of the Sun or Jupiter. This would be so as to avoid the danger that they could eventually come back and threaten Earth again at a later date.

It has been thought for some time that threat from comets is less than that of potentially hazardous asteroids, but recent reexamination of data from observations made in 1883 from Mexico of what is now thought to possibly be a large comet that very narrowly hit Earth. The following image suggests that humans and indeed all animal life on Earth may have escaped a very large "cosmic comet-based bullet" just a century and half ago.

The only reason that comets are considered less of a concern is really a matter of numbers and statistical probabilities. There are only scores of comets to track and be concerned about, while there are many thousands of asteroids and bolides (which are big space rocks that are smaller than asteroids but larger than mere meteorites or micrometeorites), although programs such as the NASA WISE infrared telescope (especially during its NEOWISE stage) have helped to identify a large number of the potentially hazardous asteroids. Nevertheless there is still a long way to go to get an accurate assessment of the space rocks out there that are in the range of 140 m to 1 k in diameter. The Sentinel infrared telescope might even eventually allow us to do an inventory down to the 30 m range. Statistical evidence indicates that there are tens of thousands of near-Earth objects in this range. As noted in the previous section, even a 30 m space rock can release the power of 7 terawatts which is a pretty powerful wallop.

Overview of Threats from Space Rocks

The truth is that despite serious efforts to come to grips with the danger from various types of space rocks in near-Earth orbit, there is still a long way yet to go. Scientists are, in effect, in the infancy of mapping cosmic dangers. There are many hidden dangers within the Solar System still to discover. In order to sum up the various types of danger, it is necessary to be concerned about the information provided in Table 1 below (Types of Near-Earth Objects (JPL)).

As can be seen in this chart, the Apollo group of asteroids represents 62 % of the known population, Amors represent 32 %, Atens represent 6 %, and there are only a very few Atiras and IEOs. Yet one must survey the sky for all of these different groups of asteroids because any one could be extremely dangerous.

The Sun

The Sun is the largest and most powerful object in the Solar System. The amount of energy that reaches Earth each day some 93 million miles (or 149 million kilometers) away from the Sun's surface is 10,000 times the total amount that all of humanity actually consumes. To say that the Sun is both the life force for planet Earth as well as a potentially destructive force that could also destroy

Handbook of Cosmic Hazards and Planetary Defense
DOI 10.1007/978-3-319-02847-7_85-1

Table 1 Overview of types of "Space Rocks" constituting cosmic hazards to Earth

Brief name	Description of hazard	Definition
NECs	Near-Earth comets	Typical period is less than 200 years and trajectory within 0.3 AU of Earth
NEAs	Near-Earth asteroid or potentially hazardous asteroid	Asteroids whose trajectory come within 0.3 AU of Earth
PHAs	Potentially hazardous asteroids. These are considered the most dangerous. These asteroids that come with 0.05 A.U.s. to Earth are thus within 4.65 million miles or 7.5 million kilometers of Earth	Potentially hazardous asteroids: NEAs whose Minimum Orbit Intersection Distance (MOID) with the Earth is 0.05 AU or less and whose absolute magnitude (H) is 22.0 or brighter
Atiras	NEAs which fly around the same orbit as the Earth (named after NEA Atira	Asteroids whose orbit around the Sun are within 0.0167 AU of Earth (very few Atiras exist)
Atens	Atens cut across Earth Orbit. Since this is at the apogee (or aphelion) Atens are moving at their slowest velocity. This maximizes the likelihood of collision but would likely decrease the speed of impact	NEAs which cut across the Earth's orbit twice. Its semi-major axis is less that 1.0 AU, while apogee is 1.0167 AU or less (see Fig. 4). Atens represent about 6 % of known NEAs
Apollos	Apollos have an orbit very similar to Earth. They travel inside Earth orbit at perihelion but above Earth Orbit at aphelion	These near circular orbit NEAs have a semi-major axis of less than 1.0 AU but an apogee of 1.02 AU or less. Apollos represent 62 % of all known NEAs
Amors	Earth-approaching NEAs with orbits exterior to Earth's but interior to Mars's (named after asteroid 1,221 Amor)	Those that are considered potentially hazardous are orbits between 1.017 and 1.3 A.U.s. Amors constitute about 32 % of NEAs or PHAs
IEO	Inter Earth objects	IEOs have a maximum aphelion of 0.983 AU. Only six such asteroids have been identified

Key terms
An astronomical unit: Is 93 million miles or 149 million kilometers and is the mean distance between the Earth and the Sun
Perihelion and aphelion: Perihelion is the closest approach point to the Sun, while aphelion is when that object is furthest away. (It is like perigee and apogee for a satellite orbiting Earth)
Major axis and semi-major axis: The major axis is the long distance across an ellipse, while the semi-major axis is the short distance across an ellipse
(This chart is composed from information supplied by the Jet Propulsion Laboratory)

all life is to state the obvious. Solar activity follows a well-known but not well-understood 11-year cycle that moves from solar minimum to solar maximum. The latest peak in the cycle has reached the during Fall season of 2013 (see Fig. 7).

What is known is that there are several types of destructive eruptions that come from the Sun and create hostile space weather for our planet. These are known as solar flares that are associated with sunspot activity and solar proton events (SPEs) and coronal mass ejections (CMEs) that are typically but not always associated with such flares. These eruptions (in terms of violence and frequency), follow this 11-year cycle.

A solar flare perceived from Earth is a sudden brightening on the Sun's surface and a manifestation of a very large energy eruption, like KABOOM. The amount of this energy release is equivalent to millions of atomic bombs going off all at once. The energy release if one actually uses the precise terms of physics can be up to a staggering 60,000,000,000,000,000,000,000,000 J of energy. This is equivalent to one sixth of all the energy the Sun produces each second or the same as 160 million atomic bombs each with a rated explosive power of 1 gigatons of TNT. If one were to try to compare this energy release with the power released in 1 s, it would be 25,000 times greater than the impact power of all of the parts of the comet Shoemaker-Levy when they hit Jupiter.

DOI 10.1007/978-3-319-02847-7_85-1

Fig. 7 Images from an observatory in Mexico taken in 1883

This huge energy release, or solar flare (see Fig. 8), is often also accompanied by a blast of plasma mass (or CME) being expelled from the Sun. It is Earth's good fortune that any CME must travel 93 million miles (or 149 million kilometers) before it encounters Earth's protective shield in the form of the Van Allen Belts and the world's geomagnetic field. Usually these coronal mass ejections go off harmlessly into space. This is because Earth actually constitutes a very small target at its location one astronomical unit away (Fig. 9).

Flares occur in active regions around sunspots that develop over a period of only minutes in times. Flares create radiation at all frequencies from highly energetic gamma rays and X-rays down through radio waves. Flares that are directed toward the Earth can and indeed do create radio outages. The blast of radiation can disable satellites and can be quite deadly for astronauts in space as well.

The power for these eruptions are thought to come from the magnetic energy within the Sun – perhaps just below the corona. These incredibly powerful energy releases are, as noted above, closely associated with coronal mass ejections (CMEs). The exact link between CMEs and flares is still not well established and a flare that is associated with sunspots does not always result in large scale coronal mass ejections.

In 1997 the Solar and Heliospheric Observatory (SOHO), a joint undertaking of NASA and the European Space Agency (ESA), was launched in order to study the Sun. The SOHO mission spacecraft was very successful and had a 15-year lifetime that extended through 2012. Although this spacecraft cost $1.5 billion (US), the sharing of costs between the two space agencies made this project more affordable for both of these space agencies. The SOHO research satellite was particularly designed to achieve a better understanding of the concept of harmful space weather from the Sun. Its prime mission was to understand in greater detail and cause of the powerful coronal mass ejections and their relation to the powerful solar radiation flares that occur at varying levels of intensity and frequency during the course of the Sun's 11-year cycle (NASA-SOHO 1997).

During solar max, the Sun can each day have as many as three coronal mass ejections that typically accompany violent solar flares. During the solar minimum, however, CMEs can be as few as once every 4 or 5 days. The reason for this periodic cycle of solar turmoil (in terms of both solar flares and related coronal mass ejections) is still a matter of intensive research and study. The most

DOI 10.1007/978-3-319-02847-7_85-1

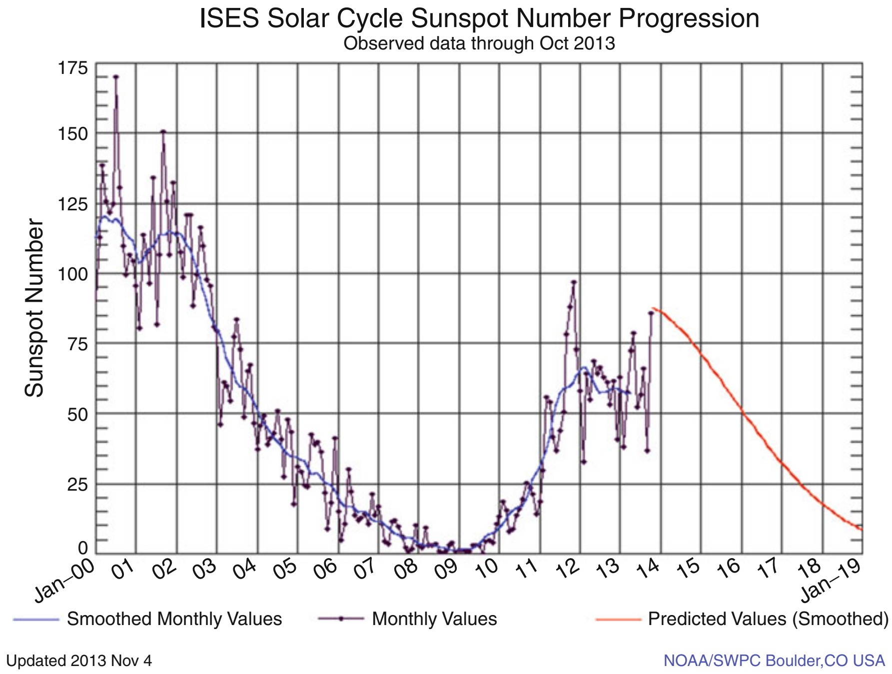


Fig. 8 Solar cycle for the period 2000–2018 (Graphic Courtesy of the U.S. National Oceanic and Atmospheric Administration)

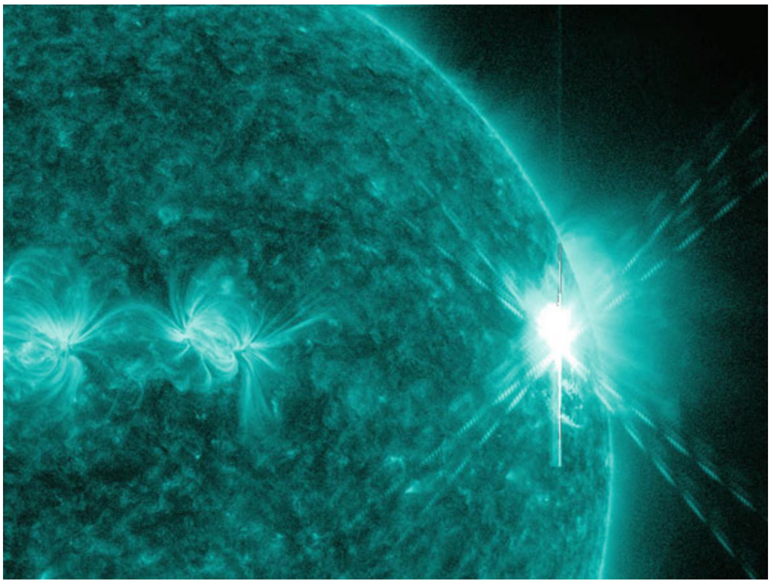


Fig. 9 A solar flare emission from a sunspot (shown in false color to reflect radiation patterns) (Image Courtesy of NASA)

puzzling enigma is why intense solar weather eruptions from the Sun can be 15 times more frequent during solar max in comparison to the more dormant conditions solar minimum (in this case "dormant" only makes sense by comparing conditions to the much more turbulent conditions during solar max).

There must be a reason why the nuclear fusion engine that generates so much solar heat and generates great loops of magnetic flux follows with such great regularity this well-documented

DOI 10.1007/978-3-319-02847-7_85-1

11-year cycle. Despite targeted research the reason for this rather precise cycle has eluded solar scientists to date.

The SOHO mission nevertheless added new levels of understanding. It is now understood that while the mass ejections do indeed spew forth from the corona, solar flares, in contrast, are now thought to be emitted from the layer of the Sun underneath the corona where sunspots form. High-intensity radiation flares and coronal mass ejections can occur in parallel or separately. Both become more intense and frequent during solar max. SOHO has allowed NASA and ESA scientists to capture 3-D images of sunspots that form below the Sun's super-hot corona (i.e., 1,000,00° C). It also allowed a better understanding of so-called slow and fast solar wind. The greater understanding of flares and CMEs has allowed up to 3 days warning of intense solar weather conditions.

NASA also launched the Advanced Composition Explorer (ACE) satellite in 1997 to study solar activities, and then in 2006, it launched two additional solar research satellites appropriately known as "Stereo." The Stereo name comes from the fact that the two satellites will fly in formation so that eruptions from the Sun can be imaged in 3-D by being able to record these events from two perspectives. The ACE and Stereo satellites are both focused on solar flares and coronal mass ejections, but the main emphasis is on recording slow and fast solar wind as it travels between the Sun and Earth and to study the highly destructive coronal mass ejections (CMEs) as they blast away from the Sun's corona. These satellites are thus discussed further in the next section and of course later in the handbook. These spacecraft, despite their prime focus on CMEs, have also produced useful information with regard to sunspot activity and high-energy radiation events as well.

Of prime interest in terms of studying the extreme radiation solar flares is the NASA satellite known as the Solar Dynamics Observatory. This satellite monitors flares, especially those in the M-Class up through the X-Class levels, since flares of this magnitude can create radio outages and damage to spacecraft and threaten the safety of astronauts in orbit. An X-Class event is at the highest levels, while an M-Class is ten times less energetic.

Solar flares that emanate from disconnected magnetic loops below the corona dramatically affect all layers of the solar atmosphere. These layers of the outer Sun are known as the photosphere, the chromosphere, and the corona. When the flare occurs it produces a plasma medium that is heated to tens of millions of degrees. This intense plasma accelerates electrons, protons and heavier ions of helium that exist within the Sun to velocities that can reach to near the speed of light. These flares produce radiation at all energy ranges from radio waves up to light and ultraviolet radiation. Most of the energy, however, is released as X-rays and gamma rays. The same magnetic surges that create the flares often result in coronal mass ejections as well.

Solar flares, as a result of their tremendous power, are dangerous and the ultraviolet radiation, X-rays, and gamma rays can and do blast artificial satellites in Earth orbit and zap the Earth's ionosphere. Without the Van Allen Belts, without the magnetosphere, and without the ozone layer (which mitigates these blasts and diverts the radiation toward the polar regions), humankind would be in big-time trouble. These flares disrupt long-range radio communications such as shortwave transmissions (i.e., high frequency, very high frequency, and ultra high frequency). This can adversely affect ham radio operators; radar systems; shortwave long-distance, microwave transmission; and over-the-air television transmissions. A solar flare of the highest X-Class range with the exact directionality to hit Earth square on could do even more damage.

The so-called Carrington event of 1859 was perhaps the first time that people realized the destructive power of solar events. Carrington, a solar astronomer, was observing the Sun on a "typical Thursday morning" in London when he suddenly saw the development of huge sunspots linked together on the surface of the Sun. These "spots" were many times the diameter of the Earth. Carrington was so excited that he ran downstairs to gather his staff to witness this unique event that

DOI 10.1007/978-3-319-02847-7_85-1

he hastily sketched. The massive "fast" solar wind that originated from this flare hit Earth the next day. This flare and then accompanying CME represented an unprecedented blast of solar fury in all of modern times. The Aurora Borealis was witnessed as far south as Hawaii and Cuba. There was at the time very little electrical devices in use at the time, but at several telegraph offices, paper caught on fire as the coronal mass ejection associated with the flare burned through the ionosphere to the Earth's surface (Pelton 2013).

Today in the age of widespread computers and electrical power use that permeates society, no one knows what the consequences would be if such an event were to happen again. The asteroid strike that destroyed the dinosaurs may be a once in every 600 million years event, but a "Carrington event" that involved a solar flare and a coronal mass ejection may be a once in every 100 and 50 years occurrence if not perhaps of greater frequency. On August 31, 2012, a major coronal mass ejection occurred as registered by the Solar Dynamics Observatory (SDO) satellite. The event was actually on a similar scale to the Carrington Event and the ejection speed was at 5.5 km an hour (or about 900 miles a second). If this CME had directly hit Earth, the scale of this hit might well have taken out most of the world's satellites and destroyed much of the energy grids as well.

A solar flare is also potentially dangerous in many ways as well. Its high-energy radiation might take out most communications and navigation satellites and disable much of the radar tracking systems. Fortunately the Earth's atmosphere and magnetosphere provide us reasonable levels of protection, except for such issues as skin cancer and genetic mutation. Coronal mass ejections (CMEs) will create much more severe consequences. Fortunately we receive more warning against the impact of this massive onslaught of ionic plasma.

The radiation from a flare can reach Earth in a matter of about 8 min, but the "slower" mass ejections that still travel at millions of kilometers/hour typically reach Earth a day to 2 days later. Billions of tons of the solar ionic mass traveling at these incredible velocities, if they were to travel on a trajectory to hit Earth, would create the most extensive damage possible.

Space Weather and Coronal Mass Ejections (CMEs)

As noted earlier solar flares and coronal mass ejections are closely related phenomena. The amount of energy associated with the flare is like millions of nuclear bombs going off at once, and if Earth were not 93 million miles or 149 million kilometers away from the Sun, virtually all life on Earth would be in big-time trouble. If a Carrington event were to happen today, it might actually disable many of telecommunication, remote sensing, meteorological, scientific, and military satellites. And the damage would not stop there.

A massive CME could wipe out a large percentage of the world's computers and processors not only in homes and offices but on airplanes, automobiles, and within vital infrastructure that routes transportation and utilities. Thus, this massive surge of space weather could wipe out the electronic controls for water and sewage plants as well as those that control the delivery of electrical power supplies. But the controls for power plants might quickly become a moot point. This is because there would no power to supply. The CME surge of ions that comes with a massive solar storm would also likely knock out most of the world's power transformers as well. Underground pipelines carrying fuel would not be exempt. These pipes might suddenly carry a huge electrical surge as the CME ions penetrated the ground and travel hundreds of miles (kilometers) to zap distribution lines or blow up inflammable fuels. A big-time hit by a CME is a disaster for which modern technological society is clearly not prepared. Indeed if the CME of August 31, 2012, had occurred just a week later, the Earth and humanity might have encounter the biggest natural disaster of the modern era. Assessments of

DOI 10.1007/978-3-319-02847-7_85-1

this event by NASA scientists have concluded that there is about a 12% chance that a similar extreme solar event could impact Earth within the coming decade.

In short the extent of the danger is not known. If a massive CME, like that associated with the Carrington event, did occur, would it indeed send most of human civilization back to the Stone Age? In the most extreme case, such a catastrophe (just like a massive electromagnetic pulse (EMP)) might wipe out most airplanes, trucks, buses, and automobiles by destroying their electronics and making them inoperable. It is possible that a strong enough CME would torch electrical power transformers and eliminate much of today's electrical power supply. Likewise there is no clear information as to whether such an event might serve to shut down most if not all modern telecommunications and computer networks. Within a brief period of time a truly massive wave of space weather could possibly zap through the Earth's atmosphere in a way that wipes out most of modern infrastructure. In the worst case condition, much of the world could be without power, telecommunications, reliable water and sewage systems, or modern transport. In large cities, at the very least, food supplies would very quickly become a critical problem as transportation and distribution systems rapidly begin to break down.

The exact cause of a CME and its specific relationship to a solar flare remains to be definitively explained. Nevertheless recent scientific research has tended toward the conclusion that the phenomenon known as "magnetic reconnection" is responsible for both coronal mass ejections (CMEs) and solar flares. This term refers to the violent shift of magnetic field lines that occurs when two oppositely directed magnetic fields are suddenly brought together.

It is now generally believed that "magnetic reconnection" may happen on what are characterized as solar arcades. It is currently thought that there are many loops of magnetic lines of force that occur just below the corona and that these multiple levels or arcades are defined by the extremes of these magnetic loops. These magnetic lines of force can and do quickly reconnect into a lower arcade of loops, leaving a helix of magnetic field unconnected to the rest of the arcade. The resulting unconnected helix of magnetic field is thought to be the cause of a sudden surge of energy. And this is a truly big – like in gargantuan – solar flare. The energy released can be up to 60 septillion joules. The unconnected magnetic helical field and the material that it contains may (or may not) violently expand outward to form the deadly ionic plasma that result in a coronal mass ejection – the CME. This explanation of magnetic loops disconnecting and violently reconnecting helps to provide a rationale as to why CMEs and solar flares typically erupt from sunspot regions where magnetic fields tend to be stronger. What is not at all clear is why there is an ongoing 11-year cycle where solar flares and CMEs are much less common and energetic, and then build up to solar maximum, and then die down again (Holman 2006).

There is a constant flow of space weather from the Sun that is characterized by what is called solar wind. The normal flow of particles from the Sun is sometimes called "slow" solar wind. The most recent research data from the Stereo satellites that are able to capture three-dimensional images of coronal mass ejections show that when the explosive mass ejections occur that the faster CME ions overtake the slower solar wind and in "eating up," the slower particles create an even more powerful solar weather event by the time it reaches Earth. The power of the impact on the Earth's protective shield is incredibly strong.

The artist representation of solar wind blasting into the protective Van Allen Belts and the shockwaves that this creates give some feel for the enormity of space weather. It is really not easy to convey what the force of perhaps billions of tons of ions hitting the Earth's protective shield at millions of miles (or kilometers) an hour is (Fig. 10).

The question that naturally comes to mind is this: "How likely is a CME event likely to cause global devastation to Earth and to human civilization?" The answer at this stage of scientific space

DOI 10.1007/978-3-319-02847-7_85-1

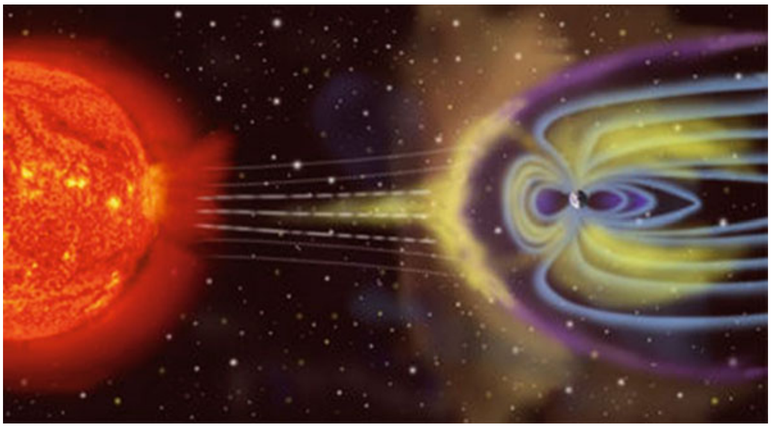


Fig. 10 Artist representation of solar weather hitting the Van Allen Belts (Graphic courtesy of NASA – note Earth is the small blue sphere)

exploration is that the answer is not known. Currently modern society is simply not prepared for something like the Carrington CME event to occur. In 1989 a much less powerful CME event, known as the Quebec event, fried transformers in Chicago, Illinois, and in Ontario and Quebec, Canada. This knocked out electronic power systems for millions of people. It is known that a very powerful CME event would be in a number of ways akin to an electromagnetic pulse (EMP) that a nuclear explosion in space would create. A single EMP event for instance could disable hundreds of millions of computers and processors that permeate the modern world.

What is known is that there are a number of key questions to pursue that fall into these two categories: How can research scientists better understand the workings of the Sun, its 11-year cycle, and especially solar flares and coronal mass ejections (CMEs)? The second set of questions relates to how to develop new or better technology to protect modern human society from a massive solar event that could potentially bring much of human civilization back to the Stone Age in virtually a blink of the eye. The dinosaurs had 1 s of warning against the giant asteroid hitting Earth. Earth might have only short warning against a massive CME, and today there is very little that can be done even if there were a day or two warning.

Cosmic Radiation

The Sun is the nearest star and it is the main source of radiation. It showers the Solar System and Earth with a tremendous amount of energy – particularly in the ultraviolet frequencies and a constant stream of X-rays and gamma rays. There are billions and billions of stars that are doing the same throughout the universe. Current understanding of the Sun, solar flares, and coronal mass ejections is derived, in part, by studying other stars in the galaxy and beyond. Stars everywhere seem to perform the same types of nuclear fusion processes and emit flares and mass ejections. Here on Earth there is a constant bombardment not only by solar radiation but by cosmic radiation that come from the nuclear reaction in stars, novae and supernovae, and even the mysterious pulsars. Some may think that all needed to be done to protect against cosmic radiation is to put on some sunscreen. Recent experience and scientific study suggest that there are dangers from cosmic radiation that truly need to be taken seriously.

It is only through Earth observation satellites that ozone holes in the upper atmosphere layers above the polar regions have been discovered. The Van Allen Belts are formed through the Earth's

DOI 10.1007/978-3-319-02847-7_85-1

magnetic field, and space weather ions are diverted from the higher latitudes toward the polar regions and accelerated as they approach the poles. It is for this reason that the Aurora Borealis and Aurora Australis (i.e., the northern and southern lights) light up the polar regions as well as create eerie noises. This aurora zones are typically 10–20° latitude from the magnetic North and South Poles. Radiation is also shielded by the Van Allen Belt and the ozone layer at the top of the stratosphere also serves to screen the most intense ultraviolet radiation. Since this most intense and powerful radiation in the UV frequencies is above the optical range, it is not directly "seen," but it can certainly be "felt." In January during the summer months in the South of Australia (Melbourne and Adelaide), Chile, New Zealand, South Africa, or Antarctica or in July the Northern parts of Canada Europe and Russia, one can certainly "feel" the intense radiation coming through.

If over time, in response to climate change and upper altitude jet and rocket combustion, the ozone holes widen even further, the danger can increase beyond concerns about sunburn. Already elevated levels of skin cancer have been recorded among those living in the high latitude areas of the world (Mirsky 2012). Even more alarming has been the detection of increased levels of genetic mutation among frogs and amphibians. There is reason to believe that if the ozone holes widen further and no protective measures taken, humans and other plant and animal lives will be subject to genetic mutation that over time could be deadly to the human species (Norby 2012). Today there has been a connection made between climate change and its impact on many parts of the world's protective biosphere. Thus, there are concerns that go beyond simply global warming to a range of concerns. Thus, scientists are beginning to explore in much greater depth such aspects as the increase in the ozone holes in the polar regions and how this could have adverse impacts that range from skin cancer to genetic mutation to plants and animals.

Geomagnetic Distortions and "Cracks"

It is a human fallacy to assume that today's reality is somehow a norm and that continuity of experience is the norm. In fact the Earth and the species of life that live on it are quite dynamic. Less than 1 % of all species that have ever lived on Earth over time exist today. The so-called K-T mass extinction event that wiped out the dinosaurs actually wiped out some two thirds of all species. There have been at least four other mass extinction events that have come not from cosmic collisions but from climate change and to be more precise due to heat increases. What is important to learn is the extent to which major changes to the Earth and the biosphere linked to what might be characterized as "cosmic events." It is thought that about every 66000 years, there is a shift in the Earth's magnetic poles. It is also suspected that when this reversal of polarity occurs, some rather dramatic shifts also occur, but there are precious little details as to exactly what to expect in terms of the impact on modern infrastructure.

Since there was no farming and fixed towns and cities nor scientific investigators before 8000 BCE, there is a great deal that is not known. A study published in 2012 by a group from the German Research Center for Geosciences suggests that a brief complete reversal occurred only 41,000 years ago during the last ice age. The reversal lasted about 440 years with the actual change of polarity lasting around 250 years. During this change, according to this study, the strength of the magnetic field dropped to 5 % of its present strength. This part of the reversal process could be a very bad problem indeed for modern electronic infrastructure. What is currently known is that after some 400 years of relative stability, the Earth's North Magnetic Pole has moved nearly 1,100 km out into the Arctic Ocean during the twentieth century and at its present rate could move from northern Canada to Siberia within the next half century.

Handbook of Cosmic Hazards and Planetary Defense
DOI 10.1007/978-3-319-02847-7_85-1

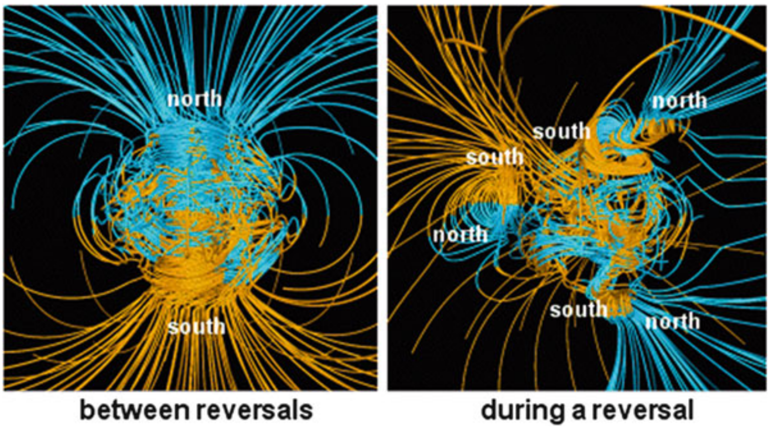


Fig. 11 Earth's magnetic field today and during a reversal (Graphic Courtesy of NASA)

The impact that this reversal of the Earth's magnetic field might have, in terms of the protective levels of the Van Allen Belts that ward off coronal mass ejections, is far from clear. The likelihood is that it could be catastrophic if not for human life – at least for all of a large percentage of today's computers, processors, and electrical power systems and much of the infrastructure that modern society completely depends on (Fig. 11).

If it is true humans do not have to worry about another polar shift and a diminished greatly geomagnetic field for several more thousand years, this would be a great relief. By the year 27,000, for instance, scientists probably will be a whole lot smarter. But what if there is not some 25000 years left? If there is a major magnetic polar shift coming much sooner, there may be big trouble ahead (Vincent et al. 2006).

And there are reasons to have some concerns as to whether "cracks" could be occurring in the Earth's magnetosphere. As early as 1961 James Dungey of the United Kingdom predicted that "cracks" might form in the Earth's magnetic shield when the solar wind contained a magnetic field that was oriented in the opposite direction to a portion of the Earth's field. In these regions with the competing two magnetic fields, it is possible that this can create a "crack" in the Earth's normal geomagnetic patterns. As noted earlier the process of "magnetic reconnection" can trigger solar flares of greater power and intensity. Here on a much more modest scale, a "magnetic reconnection" could lead to the forming of a modest crack in the Earth's shield. In this case electrically charged particles of the solar wind as well as ions from the Van Belt could flow below the geomagnetic field. This can bring not only deadly radiation but poisonous gases such as hydrogen cyanide.

These small "cracks" were first detected using the International Sun-Earth Explorer (ISEE) satellite as early as 1979. This potentially very serious threat has thus been under study since that time (The Earth's Magnetosphere Shield 2003).

A joint space mission funded by NASA and the European Space Agency, named the IMAGE satellite, has been launched to monitor these "cracks" and to determine the degree to which the Earth's geomagnetic field might be weakening and to explore whether these dangerous conditions might be increased over time.

In early January 2011 there what seemed to be a freak phenomenon where perhaps many millions of birds as well as fish were suddenly killed all at once in various locations around the world. The theory put forth by Russian scientists was that hydrogen cyanide had managed to leak through from the lower Van Allen Belt to an altitude where it could kill birds. The further theory is that this hydrogen cyanide was captured in a way that it fell with rain water and thus was able to also kill a large number of fish (Adams 2011; Stewart and Lynch 2007).

Handbook of Cosmic Hazards and Planetary Defense
DOI 10.1007/978-3-319-02847-7_85-1

If it is true that solar wind interacting with the Earth's magnetosphere can create serious cracks to let through poisonous gases or if the polarity shift is occurring earlier than expected and could cause the geomagnetosphere to reduce in strength by a factor of 20, this development could become the most severe cosmic challenge that humanity will face in the next few decades.

Antimatter and Matter Collisions

Another threat that is considered today to be obscure but may well be a hazard that should be considered with some scientific care is that of a collision between matter and antimatter. Today within the CERN nuclear accelerator, scientists are able to create minute bits of antimatter that when exposed to matter explode with tremendous force. Some researchers believe that collisions that are ascribed to an asteroid hitting Earth or exploding in the atmosphere might actually be an antimatter and matter collision.

In 2007, a supergiant star 200 times bigger than the Sun was utterly obliterated by runaway thermonuclear reactions triggered by gamma ray-driven antimatter production. The resulting blast was visible for months because it unleashed a cloud of radioactive material over 50 times the size of the Sun. SN 2007bi was discovered by the Lawrence Berkeley National Laboratory. The explosion ejected more than 22 solar masses of silicon and other heavy elements into space, including more than six solar masses of radioactive nickel which caused the expanding gases to glow brightly for many months.

Giant stars are supported against gravitational collapse by gamma ray pressure. The hotter the core, the higher the energy of these gamma rays – but if they get too energetic, these gamma rays can begin pair production: creating an electron-positron matter-antimatter pair out of pure energy as they pass an atom.

The antimatter fueled by gamma rays is generated and then this antimatter is annihilated with its opposite which is regular matter. But this is still a critical delay that allows the gamma-ray pressure to still up the star. As this process occurs the outer layers sag inward and thus compress the core more, raising the temperature, making more energetic gamma rays even more likely to make antimatter, and suddenly the whole star is a runaway nuclear reactor of almost imaginable explosive force.

The entire star explodes at once. With this type of super supernova, there is no neutron star or black hole left. The result is an expanding cloud of newly radioactive material and empty space (The Antimatter Super Nova, 2012). The question is whether a fluke event could allow a sizable amount of antimatter to collide with matter in proximity to Earth. Currently it is thought that the bulk of antimatter in the Milky Way is at the very center of the galaxy where it is extremely hot. Currently the Sun does form gamma rays but not in sufficient quantity to generate large amounts of antimatter. Some believe that the collision of antimatter and matter is not known about antimatter. The antimatter detector that is now installed on the ISS is telling us a great deal about antimatter and how it is formed. Currently the collision of matter and antimatter in a sufficient amount that it could endanger Earth and humanity seems remote, yet this phenomenon seems worthy of much more detailed study because of the enormous potential energy release – greater than any other single source in the universe known to date (Fig. 12).

Up to this point the cosmic threats that have been considered are those that come from "out there" and humanity cannot be thought to be responsible for the creation of these threats and indeed humanity's role has been to study these threats so as to eliminate or mitigate these threats through technology. But there are two types of "cosmic threat" in which humanity may well have some

DOI 10.1007/978-3-319-02847-7_85-1

Fig. 12 The colossal supernova driven by runaway gamma ray production and antimatter explosions (Graphic Courtesy of Lawrence-Berkley Laboratories)

complicity. These relate to orbital debris and the possibility that elements might return to Earth and bring with them radiological or biological agencies that could threaten life – at least to some degree – back here on Earth.

Radiological and Biological Contamination from Space

For over a half century, humans have been launching mass into orbit with little thought to the "sustainability of space." The result is that there are now about 6,500 t of mass in Earth orbit with about 2,800 t (or over 40 %) of this being low earth orbit. Some of the space objects are active satellites and spacecraft, but a good deal of it is space debris. Some of the defunct space objects contain noxious gases like hydrazine, and others contain nuclear power sources that threaten radiological contamination when they deorbit.

Rockets have lifted humans into space to explore the Moon and to carry out missions on "manned platforms." Scientists are still in early days in studying space biology and the biochemistry of life in outer space. There is far from complete knowledge about how the space environment with zero (or near zero) gravity, radiological phenomena up to gamma rays, and intense thermal gradients might affect not only the human physiology but viruses and bacteriological organisms. A major miscalculation could give rise to pandemics if mutated bacteria returned from space to the Earth environment. Certainly there are sophisticated isolation and decontamination processes for all missions returning from outer space, but only one lapse in these procedures could give rise to a deadly outbreak that could conceivably turn into a pandemic.

Even beyond human space exploration exobiology is still a young area of scientific pursuit. Some believe that organic chemistries trapped in falling meteors or bolides could bring new life-forms to Earth. In light of the huge thermal gradients that are involved this certainly seems unlikely. Yet some scientists have expressed ideas about "life-forms" that are non-carbon based such as perhaps sulfur-based life-forms that could withstand much greater heat than life-forms known to us here on Earth. As systematic ways are undertaken to prepare for planetary defense, care must be taken in all of these

Handbook of Cosmic Hazards and Planetary Defense
DOI 10.1007/978-3-319-02847-7_85-1

areas. Research activities must not prematurely rule out radiological or biological dangers that are not thought possible.

Orbital Debris

Today, concerns about orbital debris are not focused so much on the dangers of radiological or biological contamination or even space junk falling down in such a manner as to damage buildings or to kill or maim people, but rather the prime concern is focused on what is known as the Kessler Syndrome. This is the danger that was first formally anticipated by Donald Kessler in the 1980s. Kessler suggested that a "tipping point" could be reached where the buildup of space debris would continue to increase in the form of a cascade effect and that this deadly rise in space junk could endanger vital space infrastructure and thus in time make it impossible to achieve safe access to outer space.

Today radar systems are actively tracking some 22,000 objects that the size of baseball or larger. It is also known that there are some 500,000 objects that are about the size of a marble and over 100 million that are the size of a grain of salt. These space objects that are traveling at speeds of many thousands of kilometers per hour can actually be deadly to an astronaut suit. Even with new voluntary guidelines approved by the United Nation's Committee on the Peaceful Uses of Outer Space (COPUOS), the problem space debris continues to mount. Efforts are now underway to work toward active debris removal programs with a focus on the largest space debris elements because collisions of large space objects can give rise to thousands of new debris elements. With an increasing number of satellites being launched and a wide range of new small satellite initiatives, there is a need to include active debris removal in an overall program to create a planetary defense effort for Earth.

Sustainability

It is in recent times that the whole importance of "sustainability" has become apparent to people who care about the long-term survival of the human species – not for another century but for another eon. Sustainability has been defined by the Merriam-Webster dictionary as "a method of harvesting or using a resource so that the resource is not depleted or permanently damaged" (Merriam-Webster 2012).

But at its most basic level, "sustainability" means that Earth can allow human civilization to survive for the long term, and "space sustainability" means that humans will be able to access and to utilize space and space systems to survive.

At the global scale, scientific data now indicates that humans are living beyond the "carrying capacity" of the spaceship known as planet Earth. There are good rules of physics and mathematics why this cannot continue indefinitely. This scientific evidence comes from many sources but is presented in detail in such sources as the "Millennium Ecosystem Assessment (Turner 2008). A 2012 review in *Nature* by 22 international researchers expressed concerns that the Earth may be "approaching a state shift" in its biosphere (Barnosky et al. 2012).

One very useful measure human consumption is what is called an ecological footprint. This index addresses such aspects as the biologically productive land needed to provide the resources and absorb the wastes of the average global citizen. According to various studies humans are already exceeding that limit by borrowing from either the past or the future. But even if one disputes these calculations, one need only note that the total human population was 800 million in 1800, was 1.8 billion by 1900, over 6 billion by 2000, and will be somewhere in the range of 10–12 billion in 2100.

DOI 10.1007/978-3-319-02847-7_85-1

Somewhere along this exponential rise in human population, spaceship Earth has taken on too many passengers to sustain itself and to sustain itself in terms of food, power, climate, jobs, or other measures of sustainability and sanity.

If there is to be a credible plan for planetary defense, there will likely need to be some finite limits set for "one planet" consumption. In short it is not possible to divorce entirely space sustainability from sustainability here on Earth.

Structure of the Handbook

So what is the purpose of this chapter? It is to cover in a comprehensive fashion all aspects of cosmic hazards and possible strategies for contending with these threats through a comprehensive planetary defense strategy. The earlier portions of the handbook address various forms and types of threats that are poised by our cosmic environment. The middle portion of the chapter addresses the various types of scientific and observational spacecraft that helps us to better understand the physics and behavior of various types of cosmic threats. Likewise there is information presented about various ground observation activities that complement data collected from spacecraft.

The editors of this chapter have sought to bring together in a single reference work a rich blend of information about the various types of cosmic threats that are posed to human civilization by asteroids, comets, bolides, meteors, solar flares and coronal mass ejections, cosmic radiation, and other types of threats that are only recently beginning to be understood and studied. These other areas include investigation of the "cracks" in the protective shield provided by the Van Allen Belts and the geomagnetosphere and of matter-antimatter collisions, orbital debris, and radiological or biological contamination. Some areas that are addressed involve areas about which there is a good deal of information that has been collected for many decades by multiple space missions by many space agencies, observatories, and scientific researchers. Other areas involve areas of research and study that have only recently begun.

Conclusion

A concerted attempt has been made to assemble some of the world's foremost experts in each of these areas. The purpose of this effort has been to provide up-to-date and scientifically verifiable information about both the nature of these cosmic threats and possible strategies to alleviate, mitigate, or eliminate these threats. Although much of the work in these various areas have been conducted by space agencies, an expanding range of work is also being carried out by observatories, by universities and other research centers, and even by private foundations and professional organizations such as the B612 Foundation and the Planetary Society.

The purpose of this work is thus severalfold. The first objective was to provide the latest information and most systematic research from around the world in a single reference work. Secondly the goal has been to provide not only the most recent information, but where relevant the authors have sought to note where there are significant gaps in our knowledge or where new research, spacecraft, observatories, or other initiatives are needed to fill in critical missing information. Finally the third goal has been to provide the best possible information about preventative actions that might be taken against cosmic threats and to identify various alternative strategies that are now underway or planned to cope with these various threats.

DOI 10.1007/978-3-319-02847-7_85-1

Some might argue that this chapter might well have included information about the search for extraterrestrial intelligence since such cosmic life-forms could potentially pose a future threat to humanity. In light of well-documented information about the various SETI programs now underway and the current belief that livable planets are safely hundreds if not thousands of light years away, the editors have chosen not to include this topic in the chapter. Likewise, for reasons noted earlier, the issue of climate change has not been explicitly addressed since there has been so much materials addressed to this topic elsewhere.

Additional Information

The Working Group on Near-Earth Objects (WGNEO) of the International Astronomical Union held a workshop in 1995 entitled Beginning the Spaceguard Survey which led to an international organization called the Spaceguard Foundation (1995).

Cross-References

▶ Biological Hazards from Space
▶ Coronal Mass Ejections and their Cause and Nature
▶ Cosmic Radiation Management
▶ Deflecting or Disrupting a Threatening Object
▶ Earth’s Atmosphere, and the Ozone Layers
▶ Global Leadership and Strategies for Planetary Defense
▶ Institutional and Financial Arrangements for Orbital Debris Mitigation
▶ International Cooperation and Collaboration in Planetary Defense Efforts
▶ Mounting Hazards of Man-Made Orbital Debris
▶ Nature of Coronal Mass Ejections and Historical Patterns of Their Occurrence
▶ Nature of Solar Flares and Historical Patterns of Their Occurrence
▶ Planetary Defense, Global Cooperation and World Peace
▶ Potentially Hazardous Asteroids and Comets
▶ Private Initiatives: The Sentinel Project
▶ Protection Against Coronal Mass Ejections
▶ Solar and Cosmic Radiation and Hazards: The Basics
▶ United Nation Activities
▶ Van Allen Belts and What We Know and Don’t Know About Them

References

Adams M Natural news, Earth’s magnetic pole shift unleashing poisonous space clouds lined to mysterious bird deaths. http://www.naturalnews.com/030996_bird_deaths_pole_shift.html. Accessed 13 Jan 2011

Barnosky AD, Hadly EA et al (2012) Approaching a state shift in Earth’s biosphere. Nat Rev 486:52–58. doi:10.1038/nature11018

Comet Shoemaker-Levy Collision with Jupiter (1994) http://www2.jpl.nasa.gov/sl9/

DOI 10.1007/978-3-319-02847-7_85-1

"Dinosaur-killer" asteroid crater imaged for first time. National Geographic News. http://news.nationalgeographic.com/news/2003/03/0307_030307_impactcrater.html. Accessed Mar 2003

Holman G The mysterious origins of solar flares. Scientific Magazine. http://www.scientificamerican.com/article.cfm?id=the-mysterious-origins-of-solar-flares/. Accessed 26 Mar 2006

Ice age polarity was global event: extremely brief reversal of Geomagnetic field, climate variability, and super volcano. Science News. http://www.sciencedaily.com/releases/2012/10/121016084936.htm. Accessed 16 Oct 2012

Jet propulsion laboratory background on different types of orbits for potentially harmful asteroids. http://neo.jpl.nasa.gov/neo/groups.html. Accessed 9 Apr 2014

Merriam-Webster dictionary (2012) www.merriam-webster.com/dictionary/sustainable/

Mirsky S Northern lights make noise, too. Scientific American. July 11, 2012

NASA sentry risk assessment site. http://geology.about.com/gi/o.htm?zi=1/XJ&zTi=1&sdn=geology&cdn=education&tm=104&f=20&su=p284.13.342.ip_&tt=2&bt=2&bts=24&zu=http%3A//neo.jpl.nasa.gov/risk/. Accessed 9 April 2014

NASA-SOHO www.nasa.gov/mission_pages/soho/. Accessed August 2014

NEOShield (2012) The near earth object shield: preparing to protect the planet an European Union Project. http://www.neoshield.net/en/index.htm

Norby K The sunburned country: skin cancer in Australia. http://www.biology.iastate.edu/InternationalTrips/1Australia/04papers/NorbySunburn.htm. Accessed August 2014

Pelton JN (2013) Orbital debris and other threats from outer space. Springer Press, New York

Section 321 of the NASA Authorization Act of 2005 (Public Law No. 109–155), also known as the George E. Brown, Jr. Near-Earth Object Survey Act. http://www.nasa.gov/pdf/171331main_NEO_report_march07.pdf

Stewart I, Lynch J (2007) Earth: the biography. National Geographic Society, Washington, DC, pp 57–63

The antimatter supernova: one of the largest cosmic explosions ever recorded. The daily galaxy. http://www.dailygalaxy.com/my_weblog/2012/12/the-antimatter-supernova-largest-cosmic-explosion-ever-recorded.html. Accessed 28 Dec 2012

The B612 foundation and the sentinel space telescope. http://b612foundation.org/sentinelmission/

The Earth's Magnetosphere Shield. http://science.nasa.gov/science-news/science-at-nasa/2003/03dec_magneticcracks/. (Last accessed in August 2014)

The solar magnetosphere and when does it shift Poles? Global event: extremely brief reversal of GeoMagnetic field, climate variability, and super volcano. Science News. http://www.sciencedaily.com/releases/2012/10/121016084936.htm. Accessed 16 Oct 2012

The Space Guard Foundation spaceguard.iasf-roma.inaf.it/ (Last accessed in August 2014)

The Working Group on Near-Earth Objects (WGNEO) of the International Astronomical Union (September 18–22 1995) "Beginning the Spaceguard Survey". Vulcano, Italy

Turner G (2008) A comparison of the limits to growth with thirty years of reality. Commonwealth Scientific and Industrial Research Organisation (CSIRO) sustainable ecosystems

Types of near earth objects by types and grouping, JPL. http://neo.jpl.nasa.gov/neo/groups.html. Accessed 9 Apr 2014

Vincent WF, Rautio M, Pienitz P (2006) Climate control of biological UV exposure in polar and alpine aquatic ecosystems". In: Orbaek JB, Kallenborn R, Tombre IM (eds) Environmental challenges in arctic-alpine regions. Springer, New York, pp 117–157

WISE: the wide-field infrared survey explorer: the NASA infrared space telescope. http://www.nasa.gov/mission_pages/WISE/main/index.html. Accessed 9 Apr 2014