Impossible Extinction

Natural catastrophes and the supremacy of the microbial world

CHARLES S. COCKELL

CAMBRIDGE
UNIVERSITY PRESS

PUBLISHED BY THE PRESS SYNDICATE OF THE UNIVERSITY OF CAMBRIDGE
The Pitt Building, Trumpington Street, Cambridge, United Kingdom

CAMBRIDGE UNIVERSITY PRESS
The Edinburgh Building, Cambridge CB2 2RU, UK
40 West 20th Street, New York, NY 10011-4211, USA
477 Williamstown Road, Port Melbourne, VIC 3207, Australia
Ruiz de Alarcón 13, 28014 Madrid, Spain
Dock House, The Waterfront, Cape Town 8001, South Africa

http://www.cambridge.org

First published 2003

Printed in the United Kingdom at the University Press, Cambridge

Typeface Trump Mediaeval 9.5/15 pt   *System* LaTeX 2_ε [TB]

A catalogue record for this book is available from the British Library

Library of Congress Cataloguing in Publication data

Cockell, Charles.
Impossible extinction: natural catastrophes and the supremacy of the microbial world / Charles S. Cockell.
p. cm.
Includes bibliographical references and index.
ISBN 0 521 81736 6
1. Microbial ecology. 2. Extreme environments – Microbiology.
3. Extinction (Biology) 4. Catastrophes (Geology) 5. Exobiology. I. Title.
QR100 .C63 2003
579′.17–dc21 2002074046

ISBN 0 521 81736 6 hardback

Contents

1 The galactic roulette

Our lives are full of journeys, short ones and long ones, to our neighbors just down the street and our friends and cousins in other countries. But rarely do any of us consider the most important voyage that we taking part in; a voyage that takes 225 million years. And yet that is the time it takes our Solar System, the Sun and planets, to go once round our Milky Way Galaxy (Plate I). Even the Earth's orbit around the Sun, one year, is trivial compared to this immensely long galactic journey.

I recently came across a rather quaint email discussion between some amateur astronomers about this journey. One suggested that because we have a name for the time it takes for the Earth to go around the Sun (a "year") maybe we should have a name for the time it takes for the Solar System to go around the Galaxy. The email replies came in thick and fast. A "Gal-year" was one suggestion and a rather nice sounding "Milk-year" was another. You make your own decision.

This voyage began about four and a half billion* years ago when the Sun and the planets in our Solar System were formed. When life began on the Earth about half a billion years later it became an unwilling back-seat passenger in the journey. It became vulnerable to the explosions of dying stars, impacts of icy comets and rocky asteroids and the volcanic unpredictabilities of Earth's molten core during this galactic merry-go-round. To understand how we got into this journey and what might happen during its course, we need to know something about where we all came from.

* Throughout this book I will use the US rather than UK billion, that is, 1,000,000,000.

Some parents will tell their young children that babies come from under gooseberry bushes, but this isn't entirely accurate. Babies actually come from supernovas; explosions of stars that died during the formation of our Galaxy ten billion years ago. All of us are made from the atoms generated in these violent stellar explosions. Your parents merely assembled these atoms into you, but that was a much less energy-intensive task and so they shouldn't take too much credit for your existence.

The supernova explosions were part of the fireworks that heralded the formation of the Milky Way in a cloud of hydrogen gas. As with all good arguments about the Universe you are probably asking: but where did the gas cloud come from? Apparently from the Big Bang, a fiery explosion fifteen billion years ago from which all matter in the Universe emanated, including the cloud from which our Galaxy came. The origin of the Big Bang is one of those mysteries that is still being debated. My focus in this book isn't to start arguing about the merits of various cosmological theories about how the Universe began, as it has little bearing on what I want to tell you about and would take us on a great philosophical diversion. So if you will forgive my early humiliating surrender to this great question, let us start with the gas cloud, the cloud from which the Milky Way was born.

The cloud is like a billow of smoke that comes off a garden bonfire. All of us, on a fine summer evening, have sat and watched smoke coming off a fire or even a barbecue. You'll know that it is not completely regular. It has swirls or eddies in it. Smoke circles form and dissipate in many patterns, puffing out and curling in on themselves. Our galactic cloud is in some ways like this. The cloud isn't uniform and patches of smaller cloud begin to form inside the bigger cloud. The eddies begin to collapse into themselves because of gravity. As we watch the gas cloud we begin to see small blobs forming within it. These are the protogalaxies that will eventually turn into individual galaxies. One of those regions of collapsing gas is the Milky Way protogalaxy.

As the Galaxy cooled and coalesced so it began to rotate, like a spinning top. Pull the string on a spinning top and it tends to stay in one place, but the energy you put into it from pulling the string is now in the form of rotation as it whizzes round. So the energy originally imparted to our galactic cloud is partly contained within its spin. This is how we ended up on this journey around the edge of the Galaxy, the journey that this book is about. We are on the edge of a giant spinning top.

We orbit the Galaxy around a giant black hole – a star so dense that it sucks in light itself, giving it a black appearance. Although you can't see it through a telescope, the center of our Galaxy is out there in the night sky towards the constellation Sagittarius (Plate II). A rather sobering experience one evening is to take an astronomy book and locate the constellation Sagittarius and contemplate that beyond those stars is the center of the Galaxy, the point about which we are revolving on our long galactic journey. The next time humans will stand and look towards the middle of the Milky Way from roughly the same place will be in 225 million years time.

Like anyone who is curious about the neighborhood in which they live, you might be wondering where we are now. The Solar System's path around the Galaxy is not perfectly circular. If you imagine yourself looking down on the Galaxy from above you can see its Catherine wheel-like appearance (Figure 1), our distance from the center varies between about 27,000 and 31,000 light years as we go around. Right now we are moving inwards toward "perigalacticon", the point in the orbit closest to the center. As well as going round and round, the Solar System also moves up and down. If you imagine that you are now looking sideways on to the Galaxy at a spiral arm then we would be just above the middle of it, about 75 light years above the middle. We go up and down every 60 million years. We passed through the middle of the galactic arm about 2–3 million years ago and at the moment we are on our way towards the edge of our arm of the Galaxy.

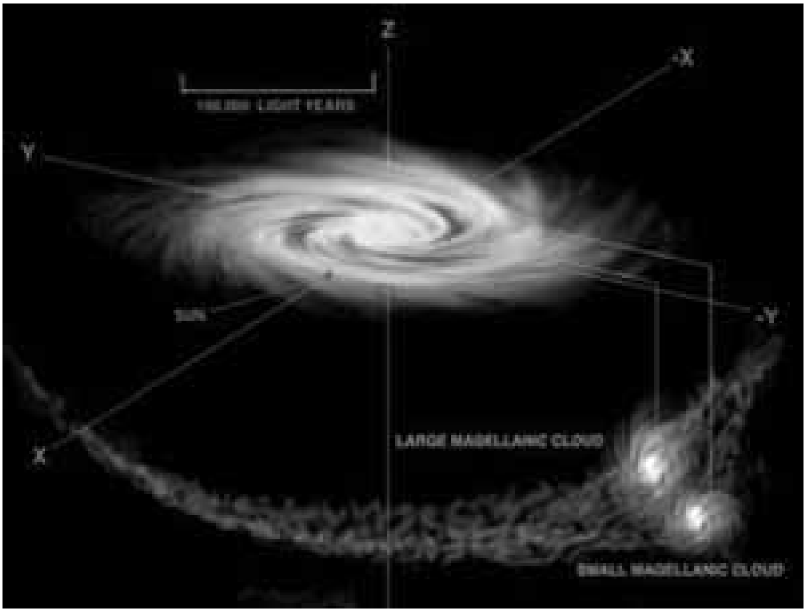

FIGURE 1. An artist's impression of our Milky Way Galaxy as seen from about 300,000 light years away. Also seen are the Magellanic Clouds, small irregular galaxies, in orbit around the Milky way. The position of our Sun is marked, and the X, Y, Z indicate the three-dimensional nature of the representation.

The Milky Way Galaxy is about 60,000 light years in diameter, about half a billion billion kilometers. To put it another way, if you started out at the edge of the Galaxy and drove to the other side at 50 miles an hour, your journey would take about a trillion years, much longer than the supposed lifetime of the Universe, so these are enormous distances. We are on the edge of an extraordinarily large spinning top.

We don't truly know what the galaxies looked like at the beginning of the Universe. Like the ancients and their view of the Earth as a disk on the back of a giant turtle, the ways we picture them are likely to be quite incorrect, a product not of our stupidity, but of the finite knowledge we have of our surroundings.

MORE ABOUT OUR LOCAL NEIGHBORHOOD

Our propensity to name places where we've been doesn't stop at holiday destinations. We are in a spiral arm of the Galaxy that we've named the Orion arm. The spacing between the spiral arms is about 4000 light years. Our neighborhood isn't exactly a throbbing hub of galactic social life, it has to be said. The density of stars is 1 star in every 300 cubic light years, with the nearest one, Proxima Centauri, 4.3 light years away or 41 trillion kilometers away, so that's quite a lonely existence. The history of our local neighborhood is actually quite exciting, so we've got that going for us. The Solar System is on the edge of an expanding shell of hot plasma about 400 light years in radius, which appears to have originated from multiple supernova explosions in a region called the Scorpius–Centaurus OB association. The shells of hot gas blown off the stars in the supernova explosions sweep material in front of them. Within this "Local Bubble", our Solar System is within a small interstellar cloud, 12 light years across, known as the Local Interstellar Cloud.

When the Hubble Space Telescope was launched into Earth Orbit in 1990 it began to yield remarkable images and information about our Universe. The telescope, being a machine, can be left to gather light from one spot in the sky for days at a time. During these long exposures it can gather pinpricks of light from galaxies that would

MORE ABOUT LIGHT YEARS

A light year is the distance traveled by light in a year. It is a confusing measurement because to the untrained eye the word "year" suggests a time period not a distance (some bad movies talk about things taking so many light years). A light year is actually 9.56 trillion kilometers. A light second is 300,000 kilometers. If you live in San Francisco and your aunt in Los Angeles, or if you live in London and your aunt lives in Edinburgh, you need to travel a two-billionth of a light year to visit her.

be impossible to see with the naked eye. The light from the galaxies seen in the Hubble Deep Field Views has taken so long to cross space and reach the Earth that we are now seeing the light given off by these galaxies during the early history of the Universe. In these images are the most primitive galaxies we have observed. Some of the furthest away, small red spots on an exposure, may have formed about fourteen and a half billion years ago. So here we are, at a stage in history where we can take photographs of the night sky from light that set out on its journey about eleven billion years before life even evolved on Earth. Imagine a photon of light formed in the gas cloud of a galaxy almost fifteen billion years ago, its ultimate destiny to hit the camera of a telescope orbiting a planet whose occupants seek to know their place in the Universe. This is the stage of human history in which we live.

Our Galaxy isn't alone in the void of space, an isolated cloud of stars. Because the protogalaxies were all forming within the gas cloud from separate swirls we would expect that there would be areas in the Universe with galactic clusters and other areas of the Universe that are quite devoid of them. This is actually what we observe. We don't find galaxies uniformly distributed, we find them collected into clusters, although the theories behind how exactly these clusters form are still quite controversial.

Humans are quite a sociable lot when it comes to our local neighborhood and we've gone to great lengths to find out who our neighbors actually are. We've called our own cluster of galaxies the "Local Group", made up of about twenty-seven galaxies and star formations of various shapes and sizes. "Local" is a relative word, of course, because this neighborhood is about three million light years across (that's thirty billion billion kilometers). The most spectacular galaxy, aside from our own, is Andromeda, another spiral galaxy about two million light years from us. Standing by our side are the Magellenic Clouds, small irregular shaped galaxies that appear to be in orbit around the Milky Way. In Figure 1 you can see an artist's impression of a view from deep in space looking back at our home.

MORE ABOUT TRAVELING LONG DISTANCES

The distances between stars and galaxies are so large that some scientists have invoked them as a reason to explain why we have not been visited by extraterrestrials. The question "If life is common in the Universe, why are we not visited by extraterrestrials?", called the Fermi paradox, is answered by the fact that distances in and between galaxies are so large that they are impossible to cross in reasonable time periods by any civilization. Hence we are bereft of friendly social visits from other civilizations. Others disagree with this and cite a number of other reasons why we don't see aliens, including that we are a scientific experiment to be observed, but not meddled with, or that we have already been visited, but can't recognize it.

On the edge of the Milky Way Galaxy is a small star that harbors our Solar System, the Earth and us. How did it come to be?

Processes in the Universe occur on the grand scale and on the tiniest scale. As the Galaxy began to form amongst the giant cluster of galaxies around it, so the galactic cloud itself began to coalesce into yet smaller fragments. These small collapsing gas clouds get hot in the middle and the radiation generated by the hot interior begins to force outwards until it resists the collapse caused by gravity pulling inwards. In the middle of this gas cloud a baby star begins to form.

Star formation happens all over the newly formed Galaxy. Everywhere where enough gas can coalesce and collapse to reach a high enough temperature for the nuclear fire to ignite, a star forms. In our Galaxy alone there are now 100 billion stars, all of which began from the swirling collapse of interstellar clouds. Our Sun is just one of these. You can only see about 2,500 stars with the naked eye on a clear night from any location on the surface of the Earth, but their white color and the bands they form is how "galaxy" got its name, from the Greek *"gala"*, meaning milk. About a quarter of the mass of the Galaxy is estimated to be in these stars, but galaxies are not very clean places. Although all we can see in the night sky are the pinpricks of light from bright stars, there are many other things out there as well. Just less than a quarter of the mass of the Galaxy is locked up in the remnants of old stars, another quarter is in interstellar clouds and then the rest is in "dark" matter. We don't know what dark matter is, but we need to hypothesize its existence to explain the stellar motions and the galactic journey that we are on. Speculation abounds about the nature of the dark matter, which includes everything from brown dwarfs, which are large objects that didn't ignite into stars, to undiscovered nuclear particles.

As the stars in the early Galaxy began to form, the temperature within them began to rise as they collapsed under gravity. The centers of the stars got so hot that protons, which are positively charged particles that came from hydrogen inside the galactic cloud, can collide with each other and form deuterium, a heavy form of hydrogen. Now when deuterium forms, it loses some mass. Albert Einstein's (1879–1955) famous equation, $E = mc^2$ explains why. You may think I'm going into too much detail, but all the equation says is that mass (m) and energy (E) can be interconverted (c is the speed of light). So when the deuterium breaks up and looses mass, this mass is converted to energy and released. What has essentially formed in our protostar is a nuclear fusion reactor and it starts to release great quantities of energy. The collision of deuterium with another proton forms helium and more mass is converted to yet more energy. Once the nuclear fire is ignited then we can truly say that a star is born.

Within this intriguing life story there is a mystery. I told you that the Galaxy and stars came from a hydrogen cloud (which maybe had a little helium mixed in as well), but you and I know that there is more in the Universe than hydrogen. There's calcium in our milk and iron in our fridge magnets. So where did these other elements come from, the elements from which life would emerge?

Imagine a hermit in an isolated log cabin in the countryside that is heated by an oil stove. One cold, harsh, winter the hermit runs out of oil and he doesn't have any money to buy more. The hermit might scour his house for something to burn to keep warm; maybe bits of wood from cutting up the furniture. Eventually as he got more desperate he would turn to successively different forms of energy to keep warm; perhaps burning bits of wet branches from trees and maybe even his old carpet. Finally, he would run out of things to burn and our poor hermit starts to go cold.

In a similar way, stars begin to run through different energy reserves. They start with hydrogen, and then move to helium. As this process goes on atoms fuse together to form heavier and heavier atoms to make the fuel that the star is burning. Interesting things are going on. Carbon might fuse with helium and form oxygen – the gas that you'll need to breathe. Oxygen atoms can fuse together to form sulfur and phosphorus – and there's your lawn fertilizer. And so, through this process, the various heavy elements we are familiar with are formed in the star. All the elements needed to make life are formed in this way. Everything that is in your house, every object you take for granted including yourself, owes its existence to the fusion reactions occurring inside the stars. The idea sounds quite simplistic, but remarkably the abundance of elements in the Universe seems to be quite well predicted by this idea. We find hydrogen is the most abundant element, followed by helium, carbon, oxygen and so on.

During the formation of these heavier and heavier elements, the core of the star begins to contract and the radiation pushing out can cause a large envelope to form around the star – a red giant is born. Inside the red giant is the core of the small star, steadily contracting as it runs through to heavier elements to burn. This little star is called a white dwarf. The mass of such a star can be formidable. If you could get hold of a tablespoon of a typical white dwarf, it would weigh about a metric tonne.

Eventually the star will use up its fuel resources and will slowly burn out like an old fire. Now and then, if the star was big enough in the beginning, the collapse of the star can be very dramatic. It can trigger a massive explosion. The explosion blows off the outer material from the star – a supernova has occurred. The star has to be just the right size to erupt into a supernova, bigger than one and a half times the mass of our own Sun. (Because this limit sets the size at which a star will go supernova, it turns out to be quite important for life because supernovas that occur near the Earth could have some dangerous consequences for life as we will see later in the book.) The stars and planets that have formed during the last five billion years, including our own Solar System, came from the material blown off by early supernovas in the Galaxy.

Today, supernovas are less common that they were during the formation of the Galaxy. It is supposed that there could have been one supernova every year in the original Milky Way and now there is less than one every ten years, possibly as few as one every one hundred years. During your lifetime there is a very good chance of at least one supernova exploding somewhere in the Milky Way, although it is unlikely you will see it. Sometimes they can occur close enough to be very spectacular. In the year 1054, the Chinese, Japanese and Koreans observed a star that was visible in daylight for three weeks and it was six times brighter than Venus in the night sky. This supernova, more formally cataloged SN (supernova) 1054, occurred in our Milky Way, and the remains are almost certainly the Crab Nebula, first observed in 1731 by astronomer John Bevis (1695–1771). It is a wonderfully colored nebula with a small rotating star in its center that sends out a pulsating signal by rotating 33 times a second. (Figure 2.)

By watching the rate at which the star is slowing down and then back-tracking, astrophysicists can work out roughly the date when the supernova explosion in the Crab Nebula was observed from the Earth. The date is about 1,000 years ago, which agrees with the observations of an explosion in 1054. (Remember though that this wasn't when the explosion itself actually occurred! Because the supernova is 6,500 light years away it took 6,500 years for the light to reach the Chinese observers. The explosion itself actually happened in about 5,500 BC, but was observed on the Earth in AD 1054.)

In 1953 at White Mesa and Navajo Canyon in Arizona, USA, an archeologist, William Miller, found Native American cave paintings dating to the beginning of the second millennium that show a bright

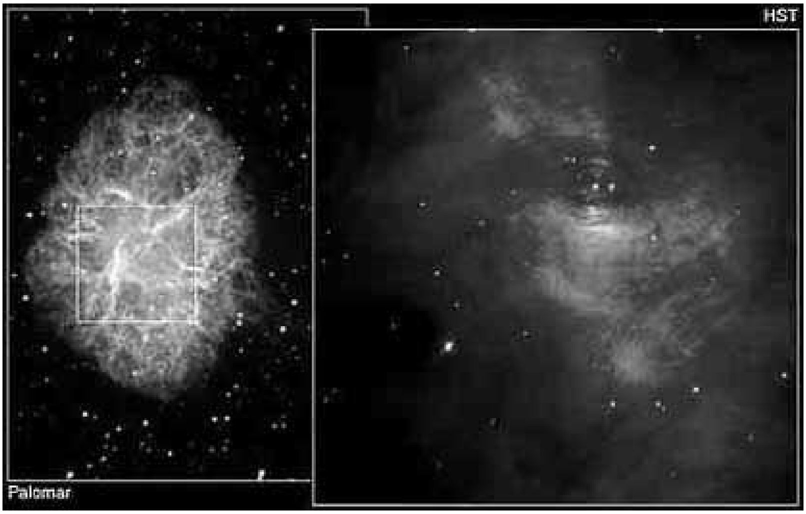

FIGURE 2. The Crab Nebula, the birthplace of a supernova observed by the ancients in AD 1054. It is from these types of explosions that the heavy elements necessary for life were formed and these explosions themselves can threaten life. On the left is the Crab Nebula as seen from Earth. On the right the Hubble Space Telescope peers into the center of the nebula and gives us an image of ripples from the pulsar, the remnant star formed during the explosion. (Image, Jeff Hester and Paul Scowen, Arizona State University and NASA.)

star next to the Moon. The position of the Crab explosion, which has been calculated to have occurred within 2 degrees of the moon, fits the cave paintings. Luckily the supernova wasn't close enough to have affected life on Earth. The radiation from it had diminished to insignificant levels by the time it had traveled 6,500 light years. It was a spectacular warning, unappreciated by the ancients, of the power of these explosions occurring around us as we rotate around the Galaxy on our journey.

I might have given you the impression that stars begin their lives, burn through their fuel, and then, if they are big enough, explode as supernovas. This is basically right, but the process can take a very long time. As we've already seen, they start off their lives as bright, fiery, tempestuous things, but once the nuclear furnace is ignited and given a few million years, they settle down into adult life and become a little less erratic. This period of adult life, called the *main sequence*, takes up about three-quarters of a star's lifetime.

Because the main sequence takes up most of a star's lifetime before it burns out or turns into a supernova, a snapshot of our Galaxy will reveal that the majority of stars will be in this stage. Over 90% of the stars we observe in our Galaxy are in the main sequence. In some ways, you can think of this as like our society. Because the adult portion of our lives takes up more time than our childhood years, at any given time a snapshot of society will reveal that most people are adults. And for stars this adult life can go on for quite a while. Our own Sun is about 4.7 billion years old and will stay in the main sequence, probably for about another five billion years.

Oh Be a Fine Girl, Kiss Me Right Now or Soon. This splendid mnemonic, although probably one that is not very politically correct these days, is an easy way of remembering that not all stars are born equal. The different star types, OBFGKMRNS, a quite illogical series of letters, reflect a decreasing surface temperature of the star from left to right. The temperature of the star will depend upon its age and how much mass it had when it started. Our own Sun, which is a G-type star and has a temperature of about 6000 °C, is less common than the cooler K-type stars found in the Galaxy that have temperatures of about 4,500 °C. You'll remember that I told you that stars that turn into supernovas tend to be the larger stars that exceed the limit needed to make them violently collapse. These are often the O- and B-type stars. So stars not only have a life history, but like people, they also come in all sorts of sizes and vary in their fieriness or placidness. Astronomers Henry Russell (1877–1957) and Ejnar Hertzsprung (1873–1967) were the first to propose a graph of this life history, a graph that obviously then became known as the Hertzsprung–Russell diagram. It is in many ways the most basic and essential classification system for anyone interested in the evolution of stars. All stars follow the life story it represents, including our own.

Of the future of our own Sun in this emerging picture of stellar evolution we are not quite sure, but it is believed that in about five billion years it will leave the main sequence and begin to expand into a red giant. First the innermost planet Mercury will be vaporized, then Venus, already a hot cauldron of volcanism bubbling away at 464 °C. The oceans of the Earth will begin to boil and life on the land will be extinguished as the planet becomes fit only for heat-loving microbes. Eventually the Earth itself will boil and vaporize and at this point all life on it will be extinguished. Until this time the Sun and the Earth will continue on their galactic journey. We will complete another twenty-five rotations around the Milky Way.