Introduction
Understanding catastrophe

GEOFFREY LLOYD

How, in a world of ever-increasing specialisation, can effective communication be maintained? This is not just a matter of communication *between* different fields of technical knowledge, but also often *within* them. It is no longer merely the old problem of the two cultures and of the gap that separates the arts and the sciences. Within each of the broad areas into which the natural sciences, the social sciences and the humanities are customarily divided, there are considerable obstacles to the exchange of ideas and information. It is not just biologists and physicists, but also mathematicians who may find the work of other mathematicians inscrutable. It is not just to scientists that the technical language of philosophers, literary critics, and historians, may seem just so much jargon.

Efforts at cross-disciplinary communication often sadly amount to forlorn attempts at popularisation, where much of the technical content is drastically over-simplified or omitted altogether. Yet opportunities for significant cross-disciplinary exchange exist, notably where several different fields make use of the same or similar key concepts or methods – or where debate focuses on similar problems or exhibits cognate preoccupations. Here, when specialists in each of several areas are prepared to pool ideas, new insights may emerge and the debate may be advanced when the issues are seen in a fresh multi-disciplinary perspective.

Cambridge University Press
978-0-521-03219-3 - Understanding Catastrophe
Edited by Janine Bourriau
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More information

In 1986 Darwin College, Cambridge, inaugurated a lecture series that aimed to promote the inter-disciplinary exploration of fundamental concepts. World experts from a variety of specialisations are invited to participate first in a series of public lectures, then in a joint publication in which they tackle issues of great contemporary importance. Each contributor is given a free hand to discuss those aspects of the general theme that appear most interesting or problematic. Following successful series devoted to *Origins, The Fragile Environment*, and *Ways of Communicating*, the topic chosen for the 1990 series was *Understanding Catastrophe*.

Catastrophe is a theme that offers particularly exciting prospects for cross-disciplinary exploration. The concept is used in a variety of areas in the natural sciences, in mathematics, in archaeology, in history, and in ecology especially. In the sequence of detailed studies that follow, we move broadly from the cosmological to the human.

Robert Kirshner deals with the massive astronomic catastrophe represented by the phenomenon of the supernova – the sudden collapse of the dense stellar core leading to the formation of a neutron star. We are here brought right up to date with the latest astronomical observations and experiments and with the latest theories both on supernovae themselves and on their cosmological implications.

Walter Alvarez and Frank Asaro track down possible reasons for the extinction of the dinosaurs, exploring the hypothesis that this may have been due to the catastrophic impact of extra-terrestrial objects. However, they also consider alternative hypotheses, including the possible effects of volcanism, and here too up-to-the-minute observations are brought to bear on the problems.

With Martin Rudwick, we turn to the origins of the geological debate in Darwin's day. Then, the mainstream of geological theory represented by the catastrophism of Whewell and Sedgwick was challenged by Lyell's *Principles of Geology*, a classic text for what came to be dubbed uniformitarianism, the view that natural changes can be adequately explained by postulating continual gradual alterations. As Rudwick shows, the outcome of this debate was not just a matter of the scientific data and arguments presented on either side, but also

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depended on the personalities, the prestige, and the persuasive talents of the debaters.

Christopher Zeeman in Chapter 4 explores the mathematics of catastrophe theory, and for good measure takes as his example Darwinian evolution. Here we learn that discontinuities in time, space and form are not necessarily the product of sharp discontinuities in the causal factors involved. Zeeman's argument is that such changes may be not merely consistent with the hypothesis of continuous causes, but may even be the consequence of those hypotheses.

Claudio Vita-Finzi studies earthquakes, both major and minor, and points out both their frequency and the variability of their effects. Here, and in the chapter that follows by Nicholas Cook on storms and cyclones, the question of the human response to catastrophes is explored. What planning measures are appropriate to cope with rare but predictable catastrophic events?

In Chapter 7 Peter Garnsey takes the issue of human response one stage further when he defines famine partly in terms of the breakdown of the social, political and economic order that drastic food shortage may bring about. He significantly remarks on the avoidability of many such a breakdown.

Finally, Roy Porter discusses consumption, both the disease and the economic activity now associated with consumerism. He shows how the disease has been used in different periods from the seventeenth century to the present day as a metaphor for evil, and how different attitudes towards it can be used to reveal fundamental preoccupations of both the medical profession and the society it serves.

What emerges from these wide-ranging topics is first the great variety of phenomena to which the notion of catastrophism can be applied – from those of cosmic proportions to the collapse of buildings. Second, the diversity of human response, whether practical or imaginative, gives food for thought. Third, the debate on the explanation of catastrophic events provides a focus for the investigation of changes in attitudes to the world and of the relationship of humans to it.

In these studies, world experts grapple with the fundamental problems, explore alternative hypotheses, bring to bear the newest evidence, and probe the limits of our understanding. The controversy between catastrophists and uniformitarians was at the centre of scientific debate in the nineteenth century. This book is testimony to its ongoing vitality and interest.

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1

Supernovae and stellar catastrophe

ROBERT P KIRSHNER

A series of catastrophes has brought each of us to our present state. Author and reader, the calcium and iron atoms that form our bones and blood were forged in the crucibles of stellar catastrophes – supernova explosions that took place 5 thousand million years ago. The death of stars leads to the chemical enrichment of the universe, its growth in complexity, and more particularly to the oxygen we breathe and the carbon atoms that ink the pages of this book.

STRANGER THAN FICTION

This cosmic benefaction results from the destruction of a massive star in a remarkable astronomical phenomenon where, for a few weeks, a single star shines as brightly as 10 thousand million suns, ejecting the interior of the supernova into the interstellar gas. New stars, planets, and books can be formed out of this richer mixture. In this sense, we are all made of stardust.

A supernova explosion is the sudden death of a star that results from the violent collapse of its core into a dense neutron star: an object with the mass of a star, but the size of a city. The energy released by this precipitous contraction powers the supernova, blasting the star apart, cooking its interior into new elements, and heating its atmosphere until it shines as brightly as a galaxy.

The constancy of stars is a literary cliché, but it is misleading. A squirrel may regard a redwood tree as eternal, but that is just a matter of the life span of the observer. While it is true that even short-lived stars endure for millions of years, 10 000 human generations, we know that stars change. The biography of a star from birth, through the crises of adolescence, into a productive middle age, and finally to a catastrophic end is called 'stellar evolution' by astronomers even though it is just the development of a single star. Interactions between particles that are smaller than an atom shape the events on a stellar scale and change the contents of the universe.

There is real evolution in the universe and this provides the context for supernovae: stars are found in galaxies, which have endured for 1000 generations of massive stars. The motions of the galaxies indicate that the pageant of stellar evolution is played out against a larger background of an expanding universe. The evidence is that the universe we see today evolved from a hot dense phase about 10 to 20 thousand million years ago: the Big Bang. The overall expansion and the development of structures that matter takes today, such as stars, galaxies, and the uneven distribution of galaxies in huge clusters, sheets and voids is one kind of evolution. There is also real evolution in the development of structure on the atomic scale. Stellar events take the simple forms of matter left over from the Big Bang, hydrogen and helium, and change them into more complex atoms that yield the richness of the world around us. Supernovae play the key role in the transmogrification of matter and the progressive enrichment of the Universe in heavy elements.

More than one route leads to stellar catastrophe. Here I emphasise the death of massive stars, some 20 times more massive than our sun. Stars of just a few solar masses can also meet with a violent end as supernovae, but lightweights require an accomplice to achieve this brilliant end. The tale of nuclear change and stellar collapse for massive stars is sufficiently intricate to illustrate the main ideas and, more importantly, has been subjected to an illuminating observational test, not by brilliant experimental design, but by great good fortune. Supernova 1987A, the brighest supernova since Tycho's of 1572 and

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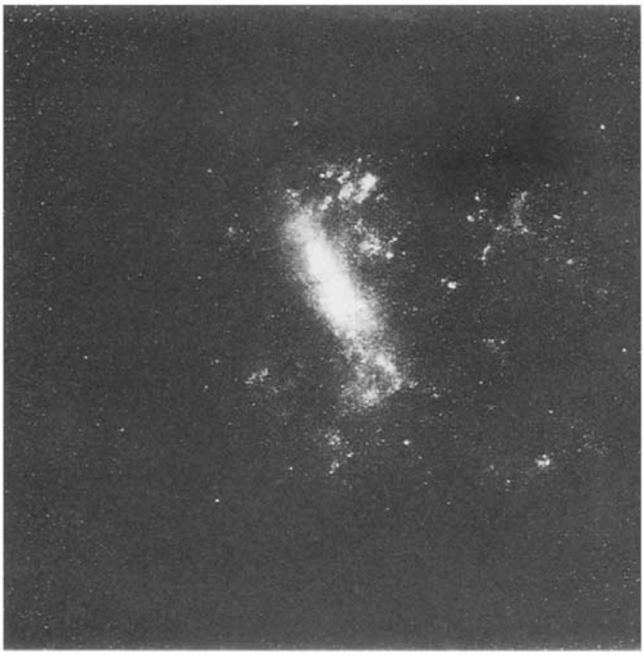

Figure 1 The Large Magellanic Cloud. The Large Magellanic Cloud is a small irregular galaxy that is a satellite of our own Milky Way Galaxy at a distance of about 150 000 light years. It has active regions of star formation where young, massive stars traverse the complete path of stellar fusion and explode in the regions where they formed. Supernova 1987A was the result of such a massive star in a region of star formation.

Kepler's of 1604, was discovered just three years ago in the nearest galaxy to our own Milky Way: the Large Magellanic Cloud (Figure 1).

THE LARGE MAGELLANIC CLOUD

Our sun is one of 100 thousand million stars in the Milky Way Galaxy, a great spinning spiral galaxy. It takes light about nine minutes to reach the earth from the Sun, and a few years for light from the Sun to reach the nearest stars. For convenience, astronomers use the term light year (LY) to indicate the distance light travels in a year. This device also has the salutary effect of reminding us that events we observe today with light gathered by telescopes are the result of

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events that took place in the past. We see the light from the Sun as the Sun was nine minutes ago, and from nearby stars as they were a few years ago. The largest dimension in the universe would be the distance that light has travelled in the time since the Big Bang, corresponding to 10–20 thousand million LY.

The diameter of our galaxy is about 100 000 LY and the typical separation of galaxies is a few million light years. Galaxies, like grapes, cluster together on scales which are 10–100 times larger, and the most extended voids and lumps in the cosmic distribution of matter are larger still. We do not yet know how large the largest structures in the universe are. We expect them to be much smaller than the 10–20 thousand million LY that characterises the size of the universe, but our current efforts at cosmic mapping have not taken us very far into those deep waters. The lives of stars hinge on details of how protons and neutrons combine. Similarly, current thinking is that the inventory and interactions of subatomic particles may also hold the key to understanding the structure of the universe on the largest scales.

Nearby structures in the universe were noted by Magellan in his 1521 world tour. Observers in southern latitudes can easily pick out the two conspicuous fuzzy patches of light we call the Large and Small Magellanic Clouds. The Large Magellanic Cloud (LMC), the site of SN 1987A, is a small galaxy of stars and gas at a distance of about 160 000 LY. Compared to the 100 000 LY span of our own galaxy, this is truly in our neighbourhood and SN 1987A was easily accessible to the whole range of modern instruments that were not available to Tycho, Kepler or any of our earlier colleagues. We are extremely fortunate to have seen this supernova in our own lives. If the LMC were just a little farther away, the light would not yet have reached us; if it were a little closer, our grandfathers would have seen the event.

The light from SN 1987A was first detected at the Las Campanas Observatory in Chile on 23 February 1987. Telescope operator Oscar Duhalde went out for a look at the sky while he put a kettle on to boil water for coffee and noticed something odd about the LMC. A few hours later, observer Ian Shelton walked over to the dome where

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Figure 2 Supernova 1987A observed on 25 February 1987.

Duhalde was working and reported he'd found a new star in the LMC. The object erupted near the part of the LMC known as the Tarantula Nebula (based on the local fauna) (Figure 3). We recognise this cloud of gas and dust as a hotbed of star birth. For the last 10 million years or so, there has been a lively baby boom of stars in this neighbourhood, leading in the end to a conspicuous bang.

STARSHINE

A star is a ball of gas held together by its own gravitation. The gas is hot enough so that gas pressure supports the star and a stable balance is reached. The problem for understanding stars is that energy is

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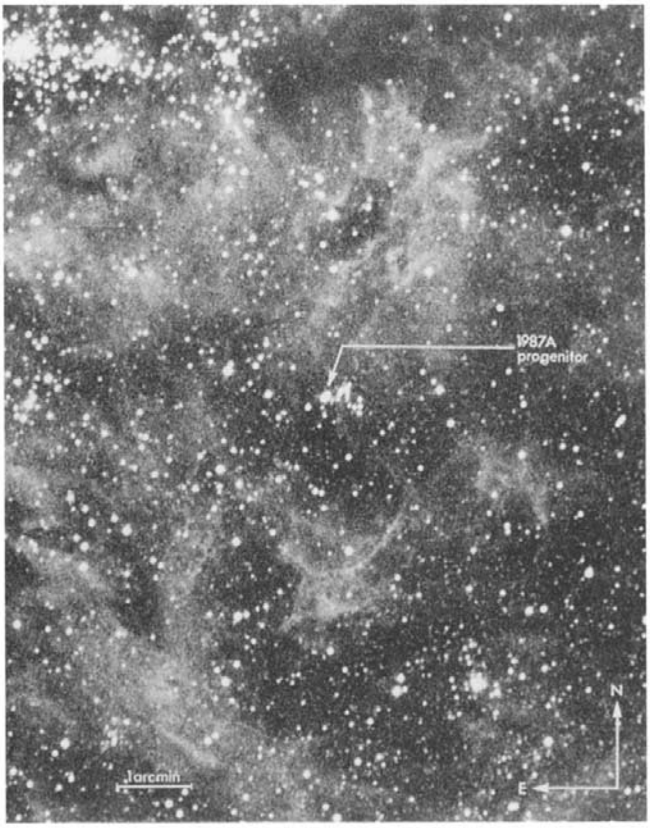

Figure 3 The site of Supernova 1987A. Measurements made after the outburst show that SN 1987A is coincident with the massive star Sk -69 202 catalogued by Sanduleak. This is the most direct evidence that supernovae come from massive stars.

escaping from the surface in the form of light. Where does the energy come from to sustain that luminosity for the lifetime of a star? This problem became very serious in the early decades of this century when the age of the Earth was determined to be about 5 thousand million years, based on the accumulation of radioactive decay products. Previous ideas that the Sun's energy source might be meteor infall or (more plausibly) gravitational contraction could only account for the Sun's output for about 20 million years. Fortunately, the same studies of radioactivity that established the age of the Earth also gave an inkling of the power source for the Sun. We now know that the Sun