the connection precise, but he manages to make the reader feel that the conservation laws are not *ex cathedra* pronouncements but derive from eminently sensible assertions about the way the Universe is constructed.

A later chapter builds on these arguments to show how local gauge invariance of the electromagnetic field, for example, demands a force to make sure that particles behave as they must towards each other. And the tautological principle that an observer cannot tell the difference between identical quantum objects leads into a nice account of Pauli's principle and exchange forces. In these sections Munowitz splendidly demonstrates how a handful of bedrock principles underlie many apparently different areas of physics. The avoidance of mathematics is a real advantage here, forcing attention on to broad concepts rather than specific rules.

From time to time I had the nagging feeling that this book may be illuminating in the way that Richard Feynman's celebrated lectures are — by striking flashes of intellectual enlightenment in readers who have already learned physics the old-fashioned way. A young Faraday of our times, looking to this book for an education, would in the end be obliged to take many of the conclusions on trust. And in a few chapters, Munowitz fumbles the conceptual continuity, delivering catalogues of things that the dutiful reader ought to know. But for any high-school student or undergraduate who is losing sight of the forest on account of all the trees, *Knowing* at times offers a persuasively harmonious view of the physicist's way of looking at the world. ■

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SCIENCE IN CULTURE

High impact

From protons to galaxies, *Cosmic Collisions* shows us what happens when things go bump.

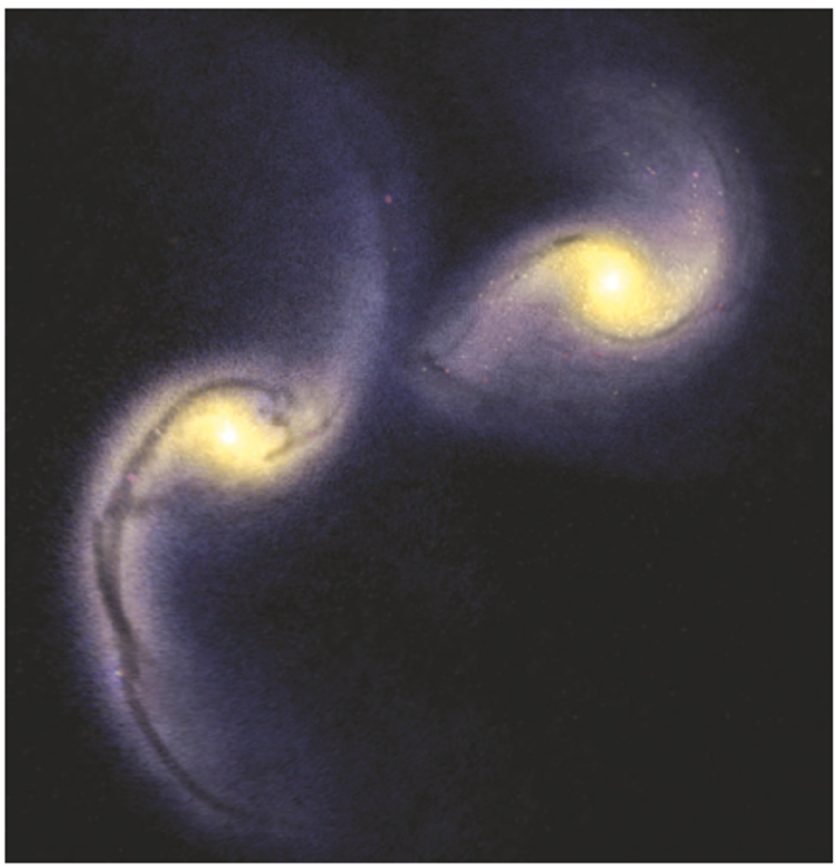
Michael Hopkin

Our galaxy is big. But it's due to get a lot bigger: in a few billion years, the Milky Way will slam into its nearest neighbour, the Andromeda Spiral, eventually creating a super-sized stellar clump. And visitors to the Hayden Planetarium at New York's American Museum of Natural History can now see a preview of the monumental event as it is likely to unfold.

The scene is the denouement of *Cosmic Collisions*, a $3-million film that reveals the power of impacts great and small to shape our world and the Universe. The project also showcases the prodigious supercomputing power now available to astrophysicists — the largely computer-generated movie visualizes some of theorists' most advanced simulations of cosmic processes.

The film focuses on impacts across a mind-boggling range of scales, from the proton collisions that power the Sun, to the asteroid smash that may have done for the dinosaurs, to the *pas de deux* of galaxies played out over millions of years.

The team behind the film, including the museum's astrophysics department, NASA and more than 25 researchers from around the world, based their pictures on supercomputer simulations and satellite images.



AM. MUS. NAT. HIST.

Forthcoming attraction: a simulation of the Milky Way's merger with Andromeda (left).

The starry sky, created using a virtual map called the Digital Universe, forms a backdrop to the film's opening, over which the gravelly tones of Robert Redford inform us that, although space might look tranquil, its myriad collisions make it a violent place.

This becomes clear during a scene in which the serenly drifting Earth is suddenly slammed by a planet-sized body that seems to appear from nowhere. This event really happened, 4.5 billion years ago, and in the space of a month it gave us our Moon. The film draws on simulations of lumps of debris being drawn together by gravity to show us how this remarkably rapid process occurred.

The film culminates with the climactic sequence in which two galaxies, each containing hundreds of billions of stars, meet. The sequence, which lasts less than a minute but in which every second represents 40 million years, is the product of more than 40,000 hours of computing time.

The galactic clash is based on simulating the behaviour of individual stars within each cluster, and comparing the results with data on real galactic collisions. Transforming that information into a visual sequence was the work of yet more supercomputers.

As for the event itself, the collision won't cause much disruption to any civilizations still around. As Redford reassures us, "Stars and planets in these galaxies won't actually collide. They're much too far apart. Scientists think they'll simply slide past one another." Nevertheless, you'll have to go a lot further than New York to get such a grandstand view of the real thing.

Cosmic Collisions is showing at the Hayden Planetarium, American Museum of Natural History, New York.

Michael Hopkin writes for *news@nature.com*.