

Preface



Sparks fly as an ancient blacksmith hammers a piece of glowing metal on his anvil. Similarly, interstellar gases are flung off the outer disk of a galaxy as a consequence of tidal forces following a close encounter with another. The gases gather in a vast plume, compressed in some regions, where gravitational forces squeeze out new star clusters, the galactic “sparks.” The smith returns his metal to the fire to be reheated. As hundreds of millions of years pass, gas in the great tidal plume falls back onto the galaxy. Some of it finds its way into the core, and fuels the hot fires of a galactic starburst, whose “coals” are hundreds of millions of newly formed stars. The smith works his metal repeatedly, tempering and strengthening it. The collision induces compression waves, which propagate through the galaxy disk, inducing more star formation, and ultimately producing a mature disk, with relatively little leftover gas.

For thousands of years the blacksmith was the master of a metal-based technology. He was as powerful and magical to his contemporaries as a modern day “rocket scientist.” His power was in his knowledge not in his ability to muster political or military resources. He was an important part of the process that led to more complex civilizations possessing much more sophisticated technologies. Galaxy collisions also play a key role in the great story of the evolution of galaxies, and the development of structure in the universe. Both stories involve the ancient “element” of fire in some sense, and both involve the refinement of metals from seemingly unpromising raw materials. In metallurgy it is the chemical refinement of raw ores. In evolving galaxies, it is the nuclear production of the chemical elements beyond helium, which astronomers call “metals.” Color images of disturbed galaxies with knots of bright young star clusters suggest an extension of the metaphor to fine jewelry. Nonetheless, despite this rather stretched metaphor, the fact remains that the world of galaxies is very different to ours.

Galaxies appear ghostly, especially when seen with the naked eye through the lenses of a small telescope. However, this is far from the truth. Galaxies are the heftiest structures in the universe, except for clusters and superclusters of galaxies. The metals produced by the generations of stars that define their evolution allowed the formation of solar systems, planets, and life forms like us. Although they appear barely visible and ephemeral on the night sky, the story of their evolution underlies the story of ours.

At first sight, galaxies appear to be very isolated entities. At least this is the way it looked to many of the astronomers who first cataloged them in the last century. It took some time to realize that galaxies can in fact fall together and

collide. The buildup of galaxies through collisions is very vigorous, even unremittingly violent, in the early ages of the universe. Only recently have we discovered that a continuing rain of small galaxies onto larger ones like our own Milky Way continues to the present time. The story of single-celled life is the continual division and propagation of daughter cells. To a large degree, the life story of galaxies is the exact opposite; continual buildup, especially in the early days.

The great story of the buildup of the largest structures in the universe is studied in two general ways. At the present time, the primary way is via large-scale studies of the statistical averages (and characteristic deviations from these averages) of many individual cases, using both observations and sophisticated computer models. We can learn much about the properties and kinds of galaxies through the ages of the universe in this way. We can learn more about the details, such as the buildup of successive populations of stars (and perhaps planets), in the second way, which is the detailed study of how specific types of collisions and mergers change galaxies. The first way is the shortest route to understanding the big picture of galaxy evolution, though the statistical details can sometimes be rather dry. The second way carries the risk of what scientists sometimes call butterfly collecting or botany – collecting many pretty examples, but not seeing the whole picture. On the other hand, there are paths to big picture truths through the study of many interesting galaxy family sagas. We will try to explore both paths, without losing our way, in the following chapters.

Galaxy collisions are a slippery topic on several levels. Firstly, it is rather hard to envision such a collision. Like continental drift, the objects and the process are just too big. Also like continental drift, the process takes a very long time. However, our minds can get around those difficulties in the same way that they get around many others, by ignoring them! In this book, I will talk about the vast galaxies with the same easy familiarity that I talk about my car, and I will describe their collision processes as though they occurred over a timescale similar to that of a typical television drama. This approach takes out a lot of the awe, but it is a practical necessity.

The second reason that the subject of this book is a bit slippery is that it involves some complex dynamical processes. One my greatest challenges has been to explain these clearly, while ruthlessly striving not to get sucked into the whirlpool of complications. We have really learned an enormous amount about these distant phenomena, using a variety of powerful physical and mathematical tools. However, most readers of this book will be more interested in the big picture (appropriately for this topic!) than the fine print. I have worked hard on this, but no doubt I have fallen short in some places.

A third slippery aspect of galaxy collisions is that it is not so much a self-contained subject as a nexus or meeting place of many other topics in astronomy and astrophysics. A little knowledge of a lot of these topics is very helpful, and again I have wrestled with providing the minimum amount of background that is necessary, and to avoid sidetracks, even if many of them are actually beautiful byways. There is another side to this coin. Because of the nature of the field,

many of the contributions have been made by researchers in related fields pursuing a sidetrack that leads in, and often relatively quickly out, of the field of galaxy collisions.

There is a core of researchers who have spent most of their careers in this field (even if it does sometimes feel more like a nomadic camp rather than a settled community), in contrast to more self-contained areas of science. Altogether, thousands of both the nomads and settled farmers of research have contributed to this field. One of the unhappiest parts of writing a book like this is accepting that even major contributions will get only a brief mention, and many significant ones none at all. Not to mention the fact that what is major is still somewhat in the eyes of the beholder in this very active field.

A consolation for these woes is the possibility of inciting an interest, or at least some curiosity, in readers new to the field. I hope this tourist brochure of the world of galaxies and their interactions will be useful as a starting point for deeper explorations. That is the primary goal of this book.

As we will see, galaxy collisions occur throughout the world of galaxies, so the study of collisions is inevitably an exploration of the galaxy world. It is very natural to pursue that exploration on a path that is parallel to the evolution of a typical collision and merger. Before beginning on that path, Chapter 1 provides some general background on the history of the discovery of galaxies, some of their systematic properties, and how they have been discovered. In this chapter, I also define some basic terminology that is used throughout the book, including Hubble's galaxy types. In Chapters 2 and 3 we begin the journey in earnest, by exploring the early stages of galaxy collisions. Many of the most beautiful forms in the world of galaxies are found in this area, and we will study a number of these individual systems.

Galaxy collisions build up galaxies, because most collisions end in the merger of the collision partners. We explore this process and its consequences in Chapters 4 and 5. The former chapter treats mergers between near equals; the latter treats the capture of smaller objects by bigger ones. One of the most spectacular consequences of galaxy collisions is the increase in the rate of star formation induced through the merger process. We consider the statistics and the physical processes behind this in Chapter 6. We will also consider the role of mergers and induced star formation in creating the phenomenon of active galactic nuclei in that chapter.

Armed with a basic understanding of galaxies and their evolution in collisions, we return to our own Local Group of galaxies in Chapter 7 in search of evidence of collisions in its history. While we find that the Local Group has been a fairly quiet village in the world of galaxies, it appears that future development is inevitable.

Finally, in Chapter 8 we take a broad look across many scales in the galaxy world. In so doing we get a better view of the environments of galaxy collisions, their cosmological context, and how the collision process is repeated on the larger scale of galaxy groups and clusters.

I have attempted to avoid unnecessary jargon and abbreviations in this book

where possible. When it is cumbersome not to, I have tried to confine the technical terms to the chapter or section where they are most relevant and used in context. However, a number of these technical terms are collected and defined in the Glossary for easy reference.

There are relatively few general reading sources on galaxy collisions; this is part of the reason that this book was written, but a number of such sources have been listed in the Resources section at the end of the book. These are sources that are relevant to every chapter in the book, while some more specific references will be given at the end of each chapter. It is hoped that all of these resources will provide a starting point for readers interested in digging deeper.



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