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CORE-COLLAPSE SUPERNOVAE

Introduction

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In the late 1930s and early 1940s it was realized that the relatively slowly varying emission from galaxies were disrupted every century by intense sources of light (for a brief time these outbursts could dominate the total light from their host galaxy). But such outbursts were short-lived and they faded over the course of weeks and months and gradually disappeared entirely making it hard to determine the actual source. At the same time, the basic building blocks of matter were becoming better and better understood and the idea of a star made up entirely of neutrons was proposed. Such a neutron star would be very compact. If a massive star collapsed down to such a compact configuration, the potential energy released could easily power a supernova explosion and this was proposed in the late 1930s. But understanding the full details of how this explosion process worked was left for future generations of scientists and a new invention, the computer.

In the 1960s, Colgate and collaborators began the first numerical calculations of explosions from the collapse of a massive star down to a neutron star. These first series of simulations found that when the collapsing stellar core reached nuclear densities, the collapse halted, sending a bounce shock through the star. This shocked stalled, but it was believed that neutrinos leaking out of the hot core (the potential energy of collapse is converted into thermal energy) would revive the shock and drive a supernova explosion. I say "believed" because, at the time, the simplistic models of core-collapse were limited by assuming an efficiency factor for neutrino deposition.

But these early simulations spawned an industry of increasingly detailed models for core-collapse supernovae, causing supernova theorists to push the frontiers of computational astrophysics combining the best numerical methods and detailed physics. The ultimate goal of these simulations has been to model supernovae in their full glory, without efficiency factors or free parameters. And in my mind, these explosive events deserve no less.

C.L. Fryer (ed.), Stellar Collapse, 3–4.

The first part of this book is dedicated to understanding neutrino-driven supernovae and the current status of the field started by Colgate and collaborators back in the 1960s. Chapter 1 discusses the massive stars whose collapse will power the supernova explosion. Chapter 2 reviews the observations. Chapters 3-5 discuss various aspects of the physics necessary to modelling stellar collapse and the neutrino-driven explosion. We end with theoretical predictions for both nucleosynthetic products and gamma-ray lines (Chs. 6-7). No book can be truly complete, and the most evident hole in this book is the lack of discussion of the equation of state used for core-collapse models. There is currently a great deal of work on this subject and I advise the reader to start with papers by Lattimer and collaborators.

The new-to-the-field reader may be concerned that small details in the physics can make an explosion succeed or fail. Indeed, many scientists think that this means that we may be missing critical physics in the explosion mechanism. That may be true, but I would argue that the supernova mechanism must depend upon the details. Why? Because massive stars are not all that different. Yet, in nature,some stars produce neutron stars and strong supernova explosions. Others collapse to form black holes and only weak or no explosions. In nature, supernova explosions seem to depend on the details. And so, as we see in the next 7 chapters, astrophysicists must also worry about those details.