PROTOPLANETARY DUST
Astrophysical and Cosmochemical Perspectives

Planet-formation studies uniquely benefit from three disciplines: astronomical observations of extrasolar planet-forming disks, analysis of material from the early Solar System, and laboratory astrophysics experiments. Pre-planetary solids, fine dust, and chondritic components are central elements linking these studies.

This book is the first comprehensive overview of planet formation, in which astronomers, cosmochemists, and laboratory astrophysicists jointly discuss the latest insights from the Spitzer and Hubble space telescopes, new interferometers, space missions including Stardust and Deep Impact, and laboratory techniques. Following the evolution of solids from their genesis through protoplanetary disks to rocky planets, the book discusses in detail how the latest results from these disciplines fit into a coherent picture. This volume provides a clear introduction and valuable reference for students and researchers in astronomy, cosmochemistry, laboratory astrophysics, and planetary sciences.

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PROTOPLANETARY DUST

Astrophysical and Cosmochemical Perspectives

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Preface

Some fundamental questions are surprisingly simple: Where did we come from? Are we alone in the Universe? These two simple questions have been pondered on and debated over by hundreds of generations. Yet, these questions proved to be very difficult to answer. Today, however, they have shifted from the realm of religious and philosophical discussions to the lecture rooms and laboratories of hard sciences: they are, indeed, among the drivers of modern astrophysics and planetary sciences.

Fortunately, and perhaps surprisingly, the Universe provides a means to address these important questions. Today we are witnessing as the answers emerge to these age-old questions. We now know that asteroids and comets of the Solar System have preserved a detailed record of the dramatic events that four billion years ago gave birth to our planetary system in only a few million years. Gravity and radiation pressure conspire to deliver almost pristine samples of the early Solar System to Earth in the form of meteorites and interplanetary dust particles. We have also taken this process one step further with the successful return of particles from the coma of comet Wild 2 by NASA's Stardust mission. Detailed chemical and mineralogical analyses of these materials allow for the reconstruction of the history of our planetary system.

We can address the questions of the ubiquity of planetary systems in our galaxy by comparing the conditions and events of the early Solar System to circumstellar disks in star-forming regions. Technological wonders, such as the Hubble and Spitzer space telescopes, have allowed direct imaging of disks in which planetary systems are thought to form and enable comparative mineralogy of dust grains hundreds of light years away.

Over the past decade these exciting advances have transformed our understanding of the origins of planetary systems. Astronomers provide exquisite observations of nascent planetary systems. Cosmochemists reconstruct the detailed history of the first ten million years of the Solar System. Circumstellar disks and, in particular,

the evolution of dust grains play a pivotal role in the formation and early evolution of planetary systems, including our own.

The chance collisions and sticking of a few tiny dust grains around a young star: these are the first steps in a long and fascinating journey that a few million years later culminate in violent, catastrophic collisions of hot, molten protoplanets as a new planetary system is born. The evolution of these dust grains and the dust disk itself is the best-studied and most-constrained phase of planet formation. We can observe dust grains as they form during the death throes of a previous generation of stars and as they are injected into interstellar space. We know that these grains are then altered by the harsh radiation fields and shock waves that propagate through the interstellar medium. Dust, concentrated into giant molecular clouds, is entrained in the gas that dominates the mass of these systems. We can identify evolutionary snapshots as some of the densest parts of clouds become unstable, collapse, and form stars surrounded by accretion disks. The dynamic and turbulent conditions in these disks lead to the evaporation, melting, crystallization, amorphization, and agglomeration of primordial and newly formed dust grains. The dust particles accrete into planetesimals, many of which persist throughout the stellar lifetime. These small bodies collide with each other, producing more dust but also, in some cases, growing to planetary bodies. This book is an attempt to synthesize our current state of knowledge of the history of this dust, from the interstellar medium where stars and planets are born to the final stages of planetary accretion using both astronomical and cosmochemical perspectives.

Astronomers study the evolution of protoplanetary disks on large scales, measuring simple, general properties of hundreds of disks. Planetary scientists, in contrast, unravel the detailed history of our Solar System by meticulous characterization of the solid remnants of the earliest epochs combined with dynamical simulation of the formation and accretion of particles from dust grains to planets. However, there has long been a disconnection between specialists in these two allied disciplines. Although they study the same processes and address the same questions, communication has been difficult because of differences in methods, concepts, terminology, instrumentation, analytical techniques, and the scientific forums where cutting-edge results are presented. This problem is not new. Twenty-seven years ago Tom Gehrels in his Introduction to *Protostars and Planets* noted the "growing separation between astronomers and planetary scientists." Although the problem persists, we believe that today astronomy and planetary science are intersecting in many places; questions where the two disciplines overlap benefit from a diversity of constraints and allow the transport of ideas and concepts. In particular, there appears to be an important convergence in the study of the origins of planetary systems.

This book builds bridges between astronomy and planetary sciences. It does so to capitalize from the value of the common questions and the different approaches.

Therefore, in designing this volume we decided from day one to merge diverse perspectives in each topic. The authors for each chapter were selected to represent distinct disciplines focused on the same question. The long, heated, and constructive discussions that ensued from pairing specialist authors with different backgrounds brought a real novel value to these chapters. This mix was further enriched by the referees' work – typically three or four for each chapter – that added diverse perspectives. They worked very hard to check the emerging text repeatedly and their essential help made this book truly a community effort.

We are immensely satisfied with the results. In the course of this work we have learned an enormous amount, from the contributing authors and also from each other. This volume presents the comprehensive history of the birth and early development of planetary systems – it provides a complex and fascinating story to partly answer a simple, yet fundamental question.

We hope you enjoy reading the book as much as we enjoyed compiling it.

Dániel Apai and Dante S. Lauretta

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