Introduction

The topics and authors for each volume of the *Annual Review of Astronomy and Astrophysics* (ARAA) are chosen by the Editorial Committee Members and their guests a few years in advance. This year's volume contains 13 articles that were largely selected and written during the COVID pandemic. We are hugely grateful to the authors for producing these excellent articles under often stressful circumstances and to the Annual Reviews production team for managing to publish this and the previous volume as planned. At the same time, we are relieved to see our professional and personal lives now returning back to normal, with many delayed in-person meetings stimulating the scientific discussions and interactions that are so important for the advancement of our field and for the development of the younger generation. This year's articles span the full range from the Sun to quasars at the edge of the Universe; although there is no common theme, the importance of characterizing different physical processes is a thread that runs through all of them.

Our volume leads off with personal reflections by Shuhua Ye, who takes us on an inspirational century-long journey through Chinese education, culture, and astronomy, from hardships during wartime years and long nights at Xujiahui Observatory to the development of very long baseline interferometry in China and frontline science at the now thriving Shanghai Astronomical Observatory. She describes her longtime efforts to build one of the most precise Universal Time systems and construct the 65-m Tianma Radio Telescope, as well as bring the Chinese, Asian-Pacific, and worldwide communities together to develop a multidisciplinary astro-geodynamical community. Throughout her fascinating career, Madam Ye has been a strong and vocal advocate for gender equality and the education and participation of women and girls in science, inspiring numerous Chinese (and beyond!) children to break the "glass ceiling." She also was the second female vice president of the International Astronomical Union from 1988–1994. Don't miss this opportunity to obtain a unique glimpse into the development of astronomy in this part of the world!

In tandem with the rapidly growing field of exoplanets, the study of planet-forming disks is undergoing a revolution thanks to the hugely powerful capabilities of the Atacama Large Millimeter/submillimeter Array, which is producing spatially resolved imaging of dust and molecules across disks. Karin Öberg, Stefano Facchini, and Dana Anderson review current insights into protoplanetary disk chemistry of the volatile CHNOPS elements from an observational and modeling perspective, highlighting the different chemical, physical, and dynamical processes that affect the abundances of species. Gas and ice compositions vary across the disk, often showing substructures that may or may not be related to those seen in the dust and which set the composition of exoplanets forming at those locations. Abundances are usually different from those of their host stars, which ultimately provides a unique tool to unravel the formation history of

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exoplanets. With first data just arriving, the article appropriately looks forward to what the *James Webb Space Telescope* (JWST) can tell us about the inner few astronomical units of disks.

Disks around young stars are also the topic of the review by Dong Lai and Diego Muñoz, but from a very different perspective, namely to channel accretion of material onto a binary star system. The time-variable physical processes that govern angular momentum transfer between the disk and the binary, as well as the secular evolution of the binaries, are discussed, including their impact on circumbinary planet formation and migration and development of eccentricities. These models can also be scaled up to "big" disks, which may be the sites of mergers of stellar-mass black holes in active galactic nucleus disks.

Astronomy is full of surprises, and one of those occurred on October 19, 2017, when the first sub-kilometer-sized object of interstellar origin passing through the Solar System was discovered, now appropriately called 1I/2017 U1 ('Oumuamua, "a messenger from afar arriving first"). Two years later, 2I/Borisov was found with very different physical characteristics, showing a comet-like tail. David Jewitt and Darryl Seligman review our current understanding of these two interstellar interlopers, which most likely originated from the protoplanetary disks of other stars, ejected by gravitational scattering from planets. This review sets the scene for the expected discovery of many more such interlopers each year by future observatories that will greatly enhance our knowledge of this fascinating population of objects.

Most observational studies of our own star, the Sun, are traditionally performed at optical wavelengths. Radio studies have long been known to provide important and unique complementary information on the physical processes, structure, and dynamics of its atmosphere. Dale Gary reviews recent high-resolution imaging of the solar radio emission at multiple frequencies and times, with highlights including measurements of the dynamic magnetic field strength, particle acceleration, and hot thermal plasma at the heart of solar flares, as well as mapping the magnetized plasma structure of the solar corona and chromosphere over a substantial range of heights.

This year's volume also features a number of articles on the Milky Way and other galaxies. Galactic dynamos are the subject of a review by Axel Brandenburg and Evangelia Ntormousi. The importance of dynamos for shaping galactic magnetic fields and components of the interstellar and circumgalactic medium (CGM) has been appreciated for decades, and the subject has seen great progress in recent years, thanks in considerable part to the application of direct numerical simulations. The article reviews this progress, with a summary of key conclusions and insights gained from recent work, and looks forward to the future of the discipline.

The interstellar medium (ISM) of the Galaxy is also the subject of a review of atomic hydrogen in the Milky Way by Naomi McClure-Griffiths, Snežana Stanimirović, and Daniel Rybarczyk. The combination of sensitive surveys of the 21-cm hydrogen line in absorption along with high-resolution lines of the HI emission are revealing new insights into the structure of the multiple HI phases and their association with magnetic fields. The authors summarize key insights and findings from this work and provide a prospectus on future observational and simulation work in the subject, including the potential to produce three-dimensional maps of the atomic ISM, which is key to understanding the physical processes at work in shaping the multiphase ISM.

Following this latter theme and reaching out to larger radii in galaxies, Claude-André Faucher-Giguère and S. Peng Oh review the physical processes shaping the CGM. As emphasized in the recently completed US Decadal Survey of Astronomy and Astrophysics, the CGM is a critical interface between galaxies themselves and the surrounding intergalactic medium (IGM), which fuels gaseous accretion and in turn is influenced by feedback of gas, metals, energy, and photons from the galaxies. In that respect, the CGM is a vital but poorly understood laboratory for studying the processes that shape this cosmic ecosystem. The review summarizes the current state of our understanding of the physical processes that shape the multiphase CGM and its interactions with the host galaxies. Key results from this rapidly growing field are described, followed by a discussion of future research directions.

Continuing along a similar theme, Robert Crain and Freeke van de Voort present a review of hydrodynamical simulations of the galaxy population. These "cosmological simulations," which track the formation of large-scale structure and the formation and hierarchical growth of galaxies, have had a profound impact on our understanding of galaxy evolution and its close coupling both to cosmology on the large scale and the formation and impacts of star and black hole formation on smaller scales. Current state-of-the-art simulations incorporate explicit treatment of gas hydrodynamics (and in some cases magnetohydrodynamic processes) and have achieved many successes in reproducing the statistical properties, scaling relations, and even gross structure and appearances of observed galaxies, all of which are reviewed in this article. The authors also review the challenges and shortcomings of the current generation of simulations, which set the agenda for future work in the field.

The beautiful images and spectra of the distant Universe emerging from JWST offer promise of finally unraveling the history of the formation of the first stars, galaxies, and supermassive black holes and the reionization of the Universe at what has become known as "Cosmic Dawn." Two very timely reviews in this volume address this exciting subject. Xiaohui Fan, Eduardo Bañados, and Robert Simcoe review observations of the highest-redshift quasars and how observations of intergalactic absorption lines arising in the IGM along the lines of sight to these quasars provide vital probes of the cosmic reionization process. A number of exciting and sometimes unexpected results from these studies are reviewed, including the surprisingly early formation of billion-solar-mass black holes and rapid evolution in both the quasar populations, host galaxies properties, and IGM properties beyond redshifts of 5–7.

Cosmic Dawn is also the subject of a review concerning what is known about the first stars, authored by Ralf Klessen and Simon Glover. This first generation of stars, often referred to as Population III, has yet to be observed directly but is a vital step in the formation of galaxies and the evolution of the Universe itself, and this importance has stimulated a large body of theoretical research. This article reviews models for the formation and evolution of these stars and their impact on their surroundings, including such important aspects as the clustering, initial mass function and mass limits, metal enrichment, and other feedback processes. Prospects for observing this first generation of stars directly or indirectly are also reviewed.

The final highlights of our volume are two articles on instrumentation and data analysis techniques, which are so vital to producing and sustaining new discoveries in our field. With the amount of astronomical data exploding exponentially, astronomers need increasingly sophisticated techniques to analyze their data sets. An important function

of ARAA is therefore to ensure that major advances in statistical methods are regularly reviewed. This volume highlights one such method for data analysis, that of Gaussian process regression. Suzanne Aigrain and Daniel Foreman-Mackey provide a highly accessible and educational introduction to this topic, which has become increasingly popular in astronomy for interpreting time-domain data sets. A well-known case is that of transiting exoplanets, where stellar variability introduces correlated noise that needs to be characterized for proper inference of the exoplanet properties. Worked examples with links to user-friendly source codes are provided: Check them out!

Our instrumentation article is a review of advances in optical and infrared interferometry, by Frank Eisenhauer, John Monnier, and Oliver Pfuhl. This technique has long held promise for revolutionizing high-resolution observations in the visible-infrared, and as explained by the authors this revolution has truly arrived over the past few years, with facilities such as the Center for High Angular Resolution Astronomy and the Very Large Telescope Interferometer (including the GRAVITY instrument), which brought breakthroughs in instrumental capability as well as delivered breakthrough scientific results. This comprehensive review takes readers from a basic introduction to the principles of interferometry to the development of facilities and the key technical advances along the way and examples of the science that has resulted. The breadth of targets and scientific applications enabled by the current generation of instruments, ranging from stars, star-forming regions, and extrasolar planets to the Galactic center and nuclei of other galaxies is one of the most impressive aspects of this revolution. The review concludes with a look to the future, with the promise of even greater progress in the era of extremely large ground-based telescopes.

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