THE MILKY WAY

BART J. BOK
AND PRISCILLA F. BOK

Fifth Edition

THE MILKY WAY

BART J. BOK

AND PRISCILLA F. BOK

Fifth Edition

Harvard University Press
Cambridge, Massachusetts, and London, England
1981

Printed in the United States of America

Library of Congress Cataloging in Publication Data

Bok, Bart Jan, 1906-
The Milky Way.

(The Harvard books on astronomy)
Includes index.
1. Milky Way. I. Bok, Priscilla Fairfield, joint author. II. Title. III. Series: Harvard books on astronomy.
QB857.7.B64 1981 523.1'13 80-22544
ISBN 0-674-57503-2

PREFACE TO THE FIFTH EDITION

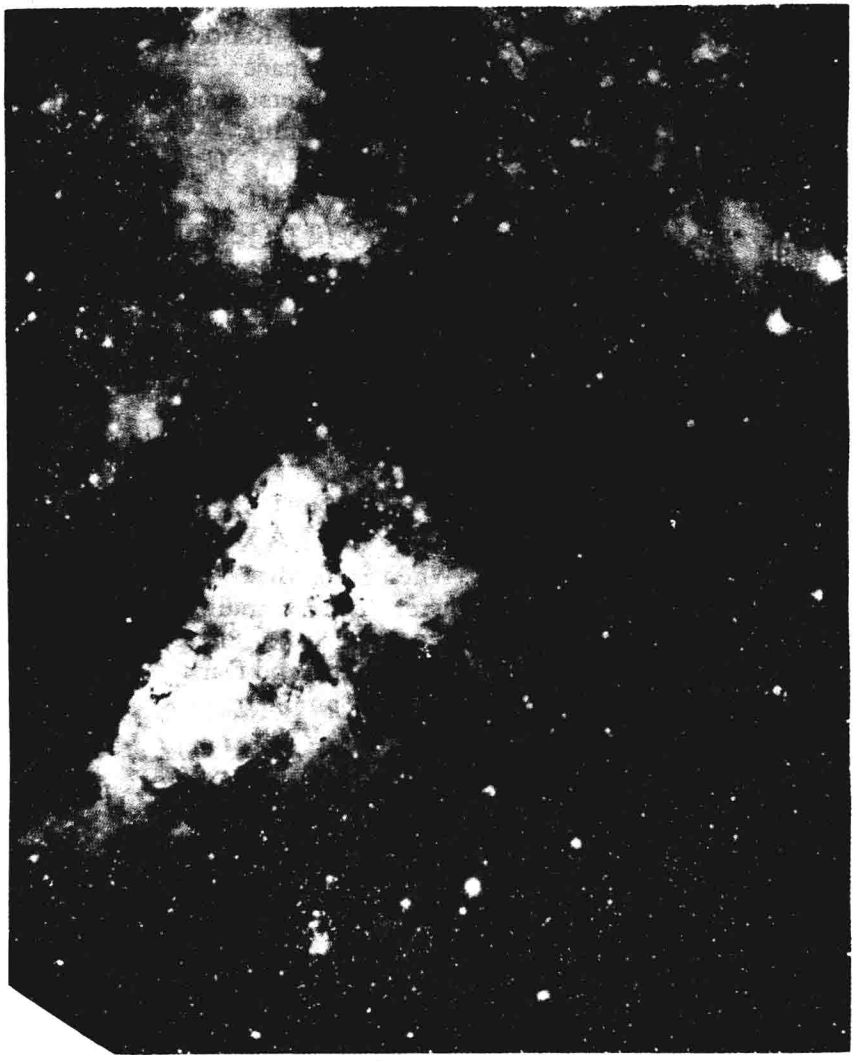
I take great pride in the Harvard Book on Astronomy that my wife, Priscilla (who died in 1975), and I first wrote in the late 1930's. As a Boy Scout in Holland at the age of twelve, I became curious about the Milky Way. Trying to satisfy that curiosity has absorbed me throughout my professional career and still gives me pleasure now that I am in my middle seventies and retired.

From the start, Priscilla and I wanted to write a book aimed specifically at beginning college students and at bright boys and girls of high-school age. Young people between thirteen and twenty were the ones for whom we liked to write, and our grandchildren were fine test objects as we were judging what to include and how to approach each subject. Quite a few of today's distinguished astronomers became acquainted with the Milky Way at an early age through the reading of our book. Another set of customers to be satisfied were the serious-minded amateur astronomers and the visitors to planetariums and science museums. In recent years a new group of readers has had to be considered: physicists, chemists, geologists, and other scientists studying the stars and the gases and dust between them. For them the Milky Way system is a giant laboratory in which the Good Lord conducts experiments (free of charge!) under conditions so extreme that we cannot hope to find—or duplicate—them here on earth.

My own interest over the years has been steadily renewed by the continual flow of developments in stellar research. In 1918, when I fell in love with the Milky Way, Harlow Shapley had just taken us from the center of the Milky Way system to the outskirts, where we belong; but the famous Washington debate between him and Heber D. Curtis was still to come. In 1924 I entered the University of Leiden, where I became closely associated with Jan H. Oort. Along with Bertil Lindblad, Oort was deeply involved in research that led to the theory of galactic rotation. The discovery by Robert J. Trumpler of a general absorbing and scattering interstellar medium did not come until 1930, and it took another twenty years until William W. Morgan and his associates, spurred on by Walter Baade, presented the outlines of galactic spiral structure. Galactic radio astronomy, which came of age in 1950 with the detection by Harold J. Ewen and Edward M. Purcell of the 21-centimeter line of neutral atomic hydrogen, was utilized with vigor for Milky Way research by Dutch and Australian astronomers. And in the middle 1960's a new tool for Milky Way research was put to work: radio molecules. Almost simultaneously, infrared astronomy permitted us to penetrate into the depths of thick, obscuring dust clouds and perceive the processes of star birth and early evolution inside these cool complexes, rich in radio molecules of many varieties.

Our book has developed along with our growing knowledge about the Milky Way system. In 1974 Priscilla and I summarized the latest developments in the fourth edition of *The Milky Way*. In keeping with past experience, we surmised that no fifth edition would be needed for fifteen years or so. Not true! Research emphasis in the field has changed considerably over the past seven or eight years, and the 1981 picture of our Home Galaxy, the Milky Way system, is very different from the 1974 model. I have spent the past couple of years revising the fourth edition to bring it in line with today's knowledge of galactic structure. As with the earlier revisions, the writing of new text and the selection of fresh illustrations to replace the outmoded ones was a real adventure. I find it great fun to write about the Milky Way—and so did Priscilla!

B.J.B.



The Great Nebula near Eta Carinae. A photograph in red (H-alpha) light made with the 1-meter Boller and Chivens reflector of Siding Spring Observatory in Australia. North is toward the bottom. The estimated distance of the nebula is 2,700 parsecs. (Courtesy of Australian National University.)

CONTENTS

1

PRESENTING THE MILKY WAY

There is a way on high, conspicuous in the clear heavens, called the Milky Way, brilliant with its own brightness. By it the gods go to the dwelling of the great Thunderer and his royal abode. Right and left of it the halls of the illustrious gods are thronged through open doors; the humbler deities dwell further away, but here the famous and mighty inhabitants of heaven have their homes. This is the region which I might make bold to call the Palatine of the Great Sky.

—*Ovid,* Metamorphoses

IN THIS BOOK we invite you to join us on a brief tour along the road to the heaven of the Greeks. Modern science is providing the transportation facilities and, without its being necessary for you to leave your comfortable chair, we would like to show you the sights. Here, briefly, is our plan.

We shall start off with a quiet evening at home, during which we shall get out maps and photographs of the territory that we are about to explore. We shall introduce you to some of the intricacies of our celestial vehicles and then we shall get under way. First we shall pay casual visits to some of the sun's nearest neighbors, but soon we shall move on to sound the real depths of our universe. We shall visit big stars and little stars and clusters of

stars within the larger Milky Way system. Between the stars we shall encounter clouds of cosmic dust and gas, some of the dust clouds so dense that they hide from our view the sights beyond. We shall, of course, linger a while on our visits to the palaces of the illustrious gods on the main road, but we shall also ask you to join us on side excursions to the places of the common people away from the well-traveled main highways.

In spite of our desire to show you all of the Milky Way system, we shall have to limit our celestial itinerary. Not infrequently along the road we shall see markers such as "Unexplored Territory," "Caution, Heavy Fog," or more encouraging signs, "Men at Work; Pass at Your Own Risk." For the Milky Way is by no means sufficiently well explored to render all of it open to celestial tourists. If you are so inclined, you may stop here and there along the road, get out your celestial Geiger counters, and do a little prospecting on your own. We hope that upon your return you will not regret having taken time for the long trip.

So, let us look at our maps and photographs and lay out the plan for journey through the Milky Way.

Map of the Milky Way

In most of the United States and Europe the best general view of the Milky Way can be had in the late summer on a moonless night an hour or so after sunset. The Northern Cross of the constellation Cygnus is then directly overhead, Arcturus is on its way down in the west, and in the northeast the W-shaped constellation of Cassiopeia is rising into view. If you are far from the glare of city lights and neon signs, you will have no difficulty in locating the shimmering band of the Milky Way, which can be traced through Cassiopeia and Cepheus to Cygnus and then down toward the horizon through the constellations of Aquila, Sagittarius, and Scorpius.

The Milky Way from Cassiopeia to Cygnus has the appearance of a single silvery band of varying width; but between Cygnus and Sagittarius we can distinguish two bands separated by a dark space called the Great Rift. The clear western branch is quite bright in Cygnus and still discernible in Aquila, but it is lost in the wastes of Ophiuchus. The head of the Great Rift is often referred to as the Northern Coalsack. Its beginning is shown nicely in Fig. 9. Visually, it is observed stretching to the south and west of Deneb, the brightest star in the constellation Cygnus.

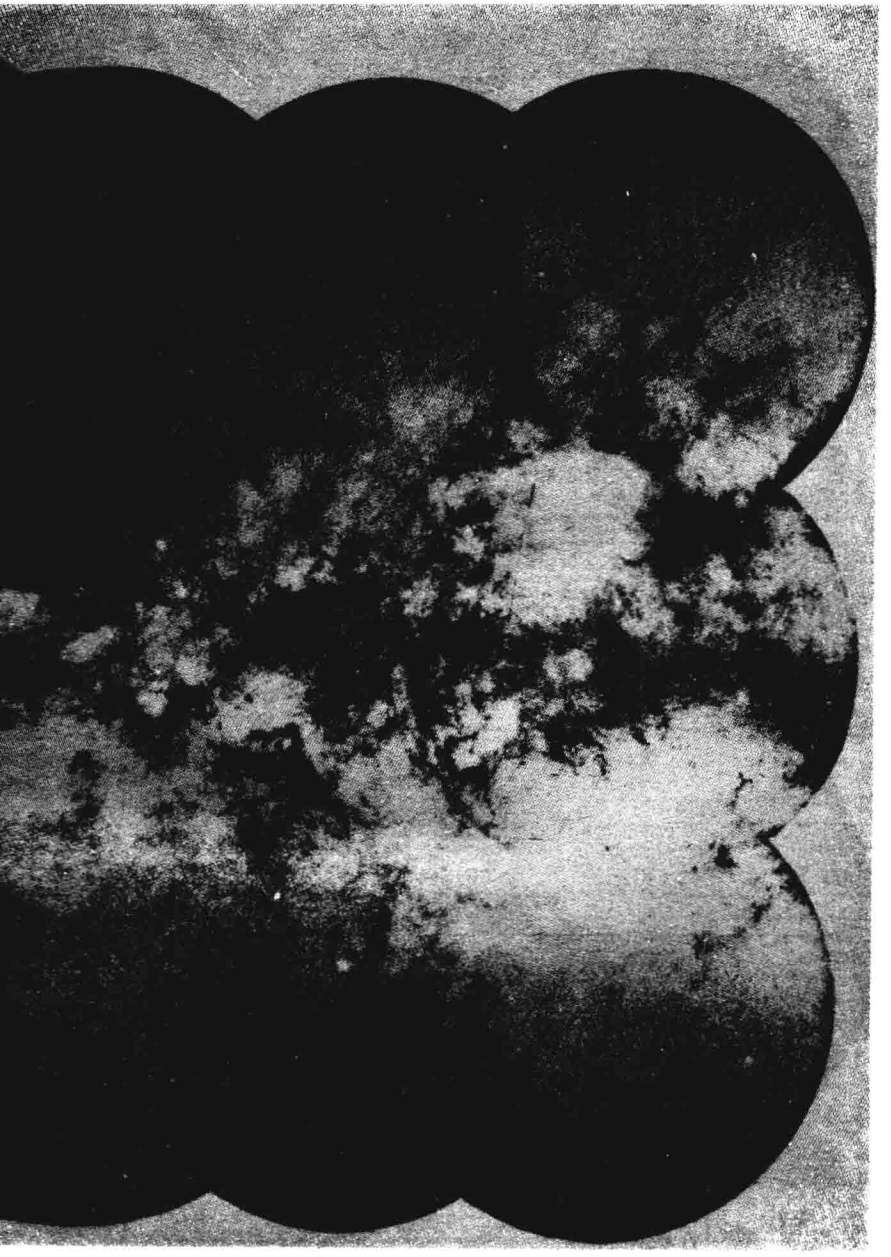
There are some very conspicuous bright spots along the summer Milky Way. The star clouds of Cygnus are directly overhead (Figs. 1 and 9). Though they put on a fine show, they lose out in comparison with the Cloud in Scutum—which Barnard called "the Gem of the Milky Way" (Fig. 7)—and with several bright clouds in Sagittarius. The Milky Way is still evident in the constellation Cepheus, but even a cursory inspection will show that north of Cygnus it does not shine nearly so brightly as does the branch to the east of the Great Rift and south of Cygnus.

What lies beyond the horizon? Our summer night progresses. Sagittarius, Aquila, and Cygnus gradually set. As Cassiopeia rises toward the meridian, other parts of the Milky Way come into view and we can follow the band through Perseus, Auriga, and Taurus; east of Taurus and Auriga it is lost in the summer dawn. But if we wait until early fall, we can follow it southward through Gemini, Orion, Monoceros, and Canis Major. The Milky Way from Cygnus through Cassiopeia to Canis Major is, however, much weaker than the branches on either side of the Great Rift. In Auriga and Taurus it narrows down to a trickling little stream that is quite insignificant in comparison with the brighter sections of the summer Milky Way.

What happens to the Milky Way south of Canis Major? It is invisible from the latitudes of New York and Paris and we shall have to travel southward if we wish to see those parts. The whole Milky Way passes in review for a year-round observer in the southern tip of Florida, but for a good view we must go down to the equator or, preferably, farther south to Chile or Peru, to South Africa, or to Australia.

The section of the Milky Way from Sagittarius through Scorpius, Norma, Circinus, Centaurus, Crux (the Southern Cross), and Carina has great brilliance. In general appearance it resembles to some extent our summer Milky Way between Cygnus and Sagittarius. The star cloud in Norma is not unlike the Scutum Cloud, and the Carina Cloud appears rather similar to the Cygnus Cloud. The southern Milky Way does not show a Great Rift, such as we find from Cygnus to Sagittarius. However, it has a remarkable "dark constellation" in the connected configuration of dark nebulae stretching from the Southern Cross to Scorpius and Ophiuchus (Fig. 102). Australian aborigines referred to it as the Emu, and its ostrich-like appearance is well known to southern observers. It is best observed in the early hours of evening in July, when the Southern Cross is high in the sky and near the meridian. The Southern Coalsack represents the Emu's head, with a sharp beak;

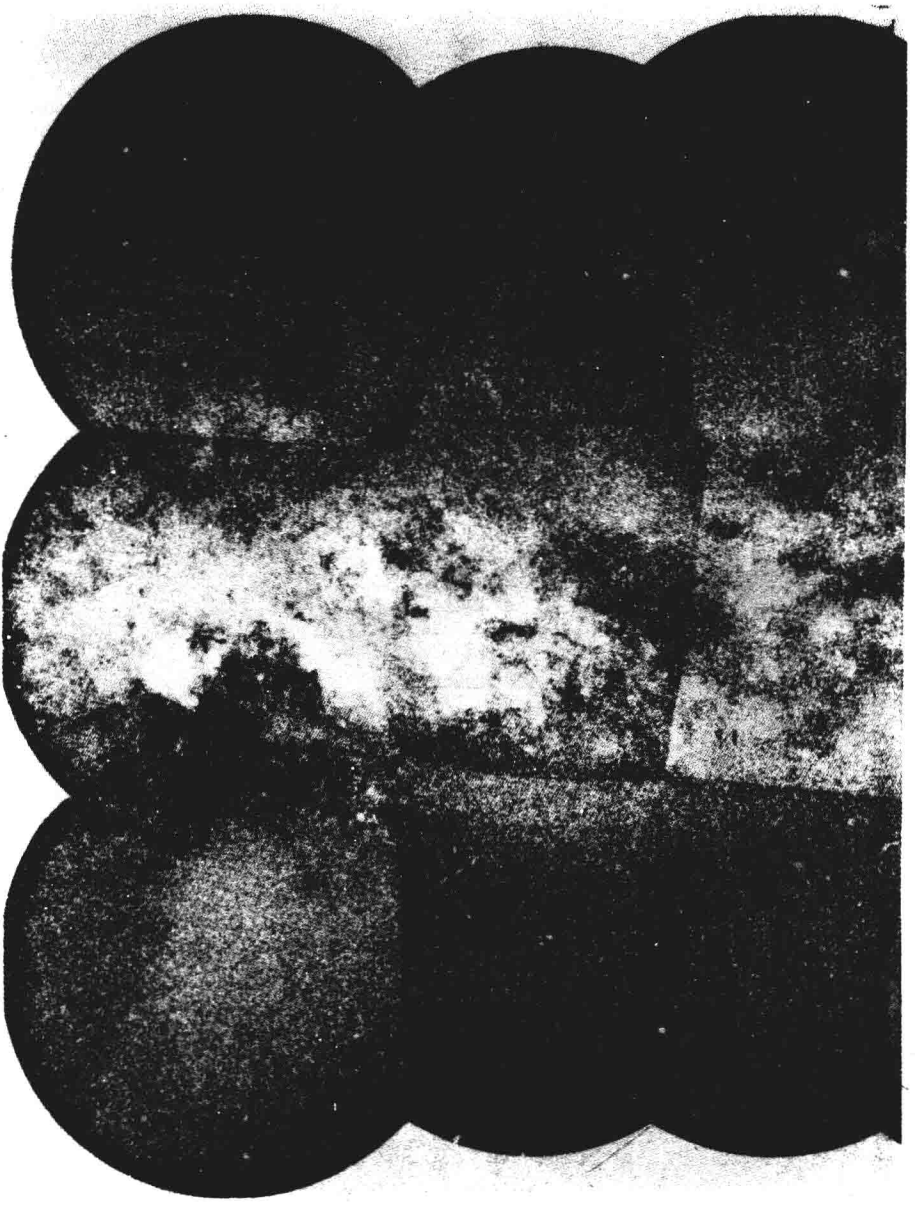
1. **The southern Milky Way from Aquila** (*at the left*) **to Sagittarius** (*on the right*). **Altair, the brightest star in Aquila, is not shown;** it is to the left of the left-hand border. The bright star cloud that is seen at the boundary of the second and third panels is the Scutum Cloud. The Great Sagittarius Cloud is the large white blob near the lower right-hand edge. This figure



is reproduced from the Mount Stromlo Observatory *Atlas* of H-alpha (red) emission in the southern Milky Way, compiled by Rodgers, Campbell, Whiteoak, Bailey, and Hunt. (Courtesy of Australian National University.)

2. The southern Milky Way from Sagittarius (*at the left*) to Norma and Ara (*on the right*). Some of the emission nebulae that make up the Sagittarius spiral arm are shown against the dark background of the three

panels on the left. This figure also has been reproduced from the Stromlo H-alpha *Atlas.* (Courtesy of Australian National University.)



3. The southern Milky Way from Centaurus (*at the left*) **through Carina and Vela to Puppis** (*on the right*). There is a gap between Figs. 2 and 3, between Norma and Centaurus, in our coverage of the southern Milky Way—that gap is filled in large measure by Fig. 91. The nebula (in Centaurus) in the left panel of Fig. 3 is shown in the second panel from the right of Fig. 91. The large white mass to the right of the Centaurus Nebula marks the Carina Nebula (the inner parts of which are shown in Fig.