



AN INSIDER'S LOOK AT MAKING SPECTACULAR IMAGES OF SPACE Dr. Travis A. Rector, Kimberly Arcand, and Megan Watzke

# COLORING THE UNIVERSE

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Dr. Travis A. Rector, Kimberly Arcand, and Megan Watzke

University of Alaska Press, Fairbanks



*Cover image by T.A. Rector (University of Alaska Anchorage) and H. Schweiker (WIYN and NAO/AURA/NSF). Formally known as IC 1396A, this dark nebula is more commonly known as the Elephant Trunk Nebula.*

*Back cover images by T.A. Rector and B.A. Wolpa (NRAO/AUI/NSF). The Eagle Nebula.*

*Author images by P. Michaud/Gemini Observatory (Rector) and Adeline & Grace photography (Arcand and Watke)*

*Cover and interior design and composition by Kristina Kachele Design, llc*

This publication was printed on acid-free paper that meets the minimum requirements for ANSI / NISO Z39.48-1992 (R2002) (Permanence of Paper for Printed Library Materials).

PRINTED IN CHINA

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University of Alaska Press  
PO Box 756240  
Fairbanks, AK 99775-6240

Library of Congress Cataloging-in-Publication Data

Rector, Travis A. (Travis Arthur)

Coloring the universe : an insider's look at making spectacular images of space /  
by Travis Rector, Kimberly Arcand, and Megan Watzke.

pages cm

Includes bibliographical references.

ISBN 978-1-60223-273-0 (cloth : alk. paper) — ISBN 978-1-60223-274-7 (e-book)

1. Space photography. I. Arcand, Kimberly K. II. Watzke, Megan K. III. Title.

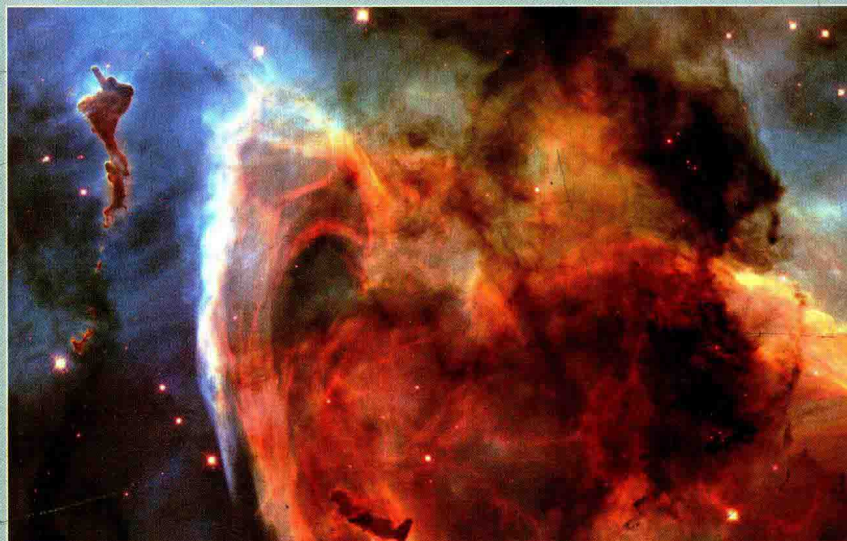
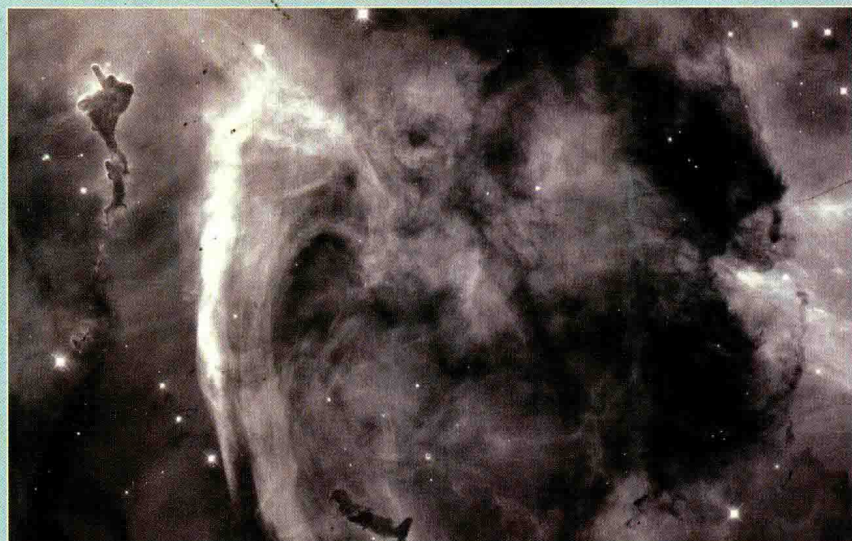
TR713.R43 2015

778.3'5—dc23

2014049536

COLORING THE UNIVERSE







# FOREWORD

The night sky has always been a mystery, since the beginning of time, or at least since our species developed the intellect to wonder. While the motions of the planets and the cycles of the seasons were appreciated thousands of years ago, the stars remained a mystery until the first telescopes were turned on them, over two hundred years ago. The simple lenses of these primitive instruments funneled more light into the eye, giving the impression of a closer view with more detail than the eye alone could achieve. This revealed that the Moon has craters and the Sun has spots; planets were seen as discs of light with unexpected features such as rings and moons. These early discoveries soon transformed our understanding of the Universe around us and of our place within it, and encouraged a way of thinking that we now call science.

A similarly transformative technology was photography, invented in 1839 and first seriously applied to nighttime astronomy about forty years later. Photographic plates and films were sensitive to radiation the eye could not see, eventually aiding the discovery of X-rays and radioactivity. However, photography rapidly revolutionized astronomy with its ability to capture and retain the impression

of faint light during long exposures, something the eye cannot do. More recently, traditional photography has given way to digital imagery, which is not only more sensitive to faint light than photography but can also be transmitted over a radio link, enabling images to be received from Earth-orbiting satellites such as the *Hubble* Space Telescope and distant space probes such as *Cassini*.

We eventually see these images as pictures, but they are initially recorded by electronic sensors and analyzed as sets of scientific data with all the power and flexibility that modern computer processing can offer. This allows the data to be manipulated and presented in ways that were never possible in an analogue photographic darkroom. However, some ideas developed in darkrooms persist in modern software.

The term “manipulated” here must not be misinterpreted. The data are manipulated to extract and reveal scientific information. That’s why the data are obtained in the first place, using sophisticated instruments and expensive facilities intended primarily for scientific research. But many scientifically oriented data sets can also be presented as images of incredible beauty, replete with information that appeals to scientist and artist alike. This often-complex process of making images that are both aesthetically pleasing and scientifically useful is at the heart of this book.

Vision is the richest of the senses, and we are used to interpreting the endless colors and varied textures of the world around us through our eyes. But even when viewed through the largest telescopes, most of the amazing star-forming nebulae and nearby galaxies that appear in these pages seem as faint gray smudges to the eye. Color is there but we cannot see it. By building up the faint signal from distant objects in an electronic detector the true colors can be revealed. But the question arises: If the colors of space have never been seen, how do you know what they should look like? That is a good and valid question, also addressed at length in these pages.

Adding to the suspicions aroused by words such as “manipulated,” the term “false color” is also used in astronomical imagery. That is when colors are used to represent data in images that have been captured at wavelengths we cannot see under any circumstance, including radio, X-ray, or infrared data. But the interpretative power of combining data that include invisible wavelengths into a single image is enormous, and to do so real colors must be used. To that extent the result is unreal, but it is not false. Indeed such images can be remarkably revealing as well as unusually eye-catching.

Finally, the authors of this book are widely experienced in creating images that include both visible and invisible light over a very wide range of wavelengths, to be used for scientific and other purposes. While the procedures for extracting the

best scientific information and the most attractive images are very similar and sometimes identical, it is also possible to emphasize the essential beauty of what is a part of the natural world for a broader audience. This too is discussed in this richly illustrated book in a nontechnical style that will appeal to specialist and novice alike.

—Dr. David Malin



## PREFACE

It's a clear August night in Mountain View, a northern neighborhood of Anchorage, Alaska. We were assembled to celebrate the grand opening of the MTS Art Gallery. Over thirty artists from the area were invited to present their work in a former mobile trailer supply store converted into an art space. While not technically an artist, I was given the opportunity to show my astronomical images on a wall in what was once a giant RV service bay. It was a room that called for something big, and I was invited to fill it with space itself.

Even though it was approaching 10:00 p.m., the bright summer night skies of Alaska meant viewers entering the darkened service bay could, at first, only see the giant images on the wall before them. It was almost as if they were walking into outer space. As they waited for their eyes to adapt to the darkness, I guided them into the gallery with my voice and answered questions. It was a rare opportunity to watch people interact with my images and freely ask what was on their mind.

"Are these real?"

"Is this what it really looks like?"

“If I were standing right next to this, is this what I would see?”

While most of the questions were eventually about what was in the images, nearly all of the first questions were about their authenticity. In a world made surreal with the magic of science-fiction special effects and digital image manipulation, there was a need to know that what we were seeing was real. That these fantastic cosmic starscapes were places that truly existed. Places perhaps we could someday visit.

The first question is easy to answer. Yes, everything you are seeing is real. These images are of real objects in outer space. They aren't creations of a graphic artist's imagination. But answering the other questions is not as simple. How a telescope “sees” is radically different from how our eyes see. Telescopes give us superhuman vision. In most cases they literally make the invisible visible.

All astronomical images, including the ones in this book, are translations of what the telescope can see into something that our human eyes can see. But how is it done? This is a question that has challenged astronomers and astrophotographers for decades. Many people, including my collaborators and me, have developed and refined techniques to take the data generated by professional-grade telescopes and turn them into color images. Along the way we've worked to develop a visual language to better convey an understanding of what these pictures show.

My coauthors, Kim Arcand and Megan Watzke, have worked in astronomy and with NASA data for almost twenty years. They have also studied how people interpret and interact with cosmic images. Together, we will show you how the scientists, visualization specialists, and public communications staff at the professional observatories create and share images of space. We'll talk about what they do and, perhaps more important, *do not do* when making an image. The knowledge we share in this book is drawn not only from our experiences but also from the expertise of the many talented individuals we've had the privilege to work with over the years. Throughout the book we've put many words and phrases in **bold** text. These are terms you are likely to see elsewhere (for example, in a science press release) and are worth knowing. We invite you to use this book to discover for yourself how the telescopes at the professional observatories are used to see and share the real Universe that we all live in.

—Dr. Travis A. Rector



# ACKNOWLEDGMENTS

We'd like to thank our agent Elizabeth Evans of the Jean V. Naggar Literary Agency and our publisher, the University of Alaska Press, for making this book a reality. We also thank the scientists, photographers, and artists who let us use their materials. If it takes a village to raise a child, it takes an entire community to learn about the wonders of the cosmos. This book would not be possible without the countless women and men who have contributed to the quest to explore our Universe and communicate that knowledge to the widest possible audiences.

The three of us are indebted to Jeffrey Bennett, Andrew Fraknoi, and David Malin for their input on earlier versions of the manuscript. Travis would like to thank the many collaborators with whom he has worked on images, especially Heidi Schweiker, Peter Michaud, Kirk Pu'uohau-Pummill, Zolt Levay, Lisa Frattare, Jayanne English, Pete Marenfeld, Mark Hanna, Tim Abbott, and Nicole van der Blik. Of course these images wouldn't be possible without the amazing telescopes and instruments at Gemini Observatory, the National Optical Astronomy Observatory (including Kitt Peak National Observatory and Cerro Tololo Interamerican Observatory), and the National Radio Astronomy Observatory,

which are owned and operated by the National Science Foundation. We also thank NASA for the many wonderful images produced by the *Hubble* Space Telescope, the *Chandra* X-ray Observatory, and the *Spitzer* Space Telescope. None of these images would be possible without the scientists, engineers, and staff who design, build, and operate all of these telescopes. This material is based upon work supported by the National Science Foundation under grant DUE-1523583. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Kim and Megan would be greatly amiss if they did not mention the support from their colleagues at the *Chandra* X-ray Observatory Center. Kim would also like to thank the Aesthetics & Astronomy (A&A) group members, Lisa and Jeffrey Smith, Randall Smith, and Jay Bookbinder, as the A&A project has informed her work in astronomy imaging.

Personally speaking, Kim could not write any books without thanking her husband, John, for his loving support, her kids, Jackson and Clara, who are her tireless cheerleaders, her parents who are her biggest fans, and her dear family and friends for all of their support. Megan is forever thankful for Kristin, Anders, Jorja, Iver, and Stella, who help guide her way through this Universe, as well as for all of the love and encouragement from friends and family. *Travis dice: Abrazos y mil besos a mi Paolita y Claudita. Son mis estrellas y el cielo.* Every star you see is how many times I think of you.





# CONTENTS

*Foreword by David Malin* viii

*Preface* xi

*Acknowledgments* xiii

## 1. HUMAN VERSUS TELESCOPE: COMPARING TELESCOPIC VISION WITH HUMAN VISION 2

*Seeing Is Believing* 2

*Three Things a Telescope Does* 4

## 2. THIS IS NOT A SELFIE: HOW TELESCOPES AND THEIR CAMERAS WORK 10

*How a “Visible-Light” Telescope Works* 10

*Starlight, Camera, Action!* 18

*Calibrating the Camera* 20

## 3. COLORING THE UNIVERSE: BROADBAND IMAGES, AND HOW WE USE COLOR 24

*Show Your True Colors* 24

*Making Color in Photography* 26  
*Putting Color into Astronomical Images* 28  
*Broadband Filters* 31

#### 4. COLOR IS KNOWLEDGE: WHAT SCIENTISTS LEARN FROM COLOR WITH BROADBAND FILTERS 34

*Stars in Living Color* 34  
*Diamonds and Dust* 40  
*The Colors of Galaxies* 40

#### 5. A BRIEF HISTORY OF ASTRONOMICAL IMAGES: THE HISTORY OF HOW (AND WHY) IMAGES ARE MADE 50

*The Era of Photographic Plates* 52  
*Astronomy for Everyone* 54  
*The Rise of the Electronic Camera* 55  
*The Year That Was 1994* 58  
*Onward to the Future* 60  
*The Time Is Now* 63

#### 6. THE MARVEL OF HYDROGEN: THE MOST IMPORTANT ELEMENT AND HOW WE SEE IT 68

*Element Number One* 68  
*The Birth of Stars* 71  
*Jets from Forming Stars* 80  
*Choosing the Colors* 86

#### 7. SEEING RED: HOW WE SEE COLOR, AND HOW WE USE IT 88

*How Our Eyes See Color* 88  
*Interpretation of Color* 91  
*Perception of Temperature* 91  
*Here and Far* 94  
*Not Paint by Numbers* 95

#### 8. NARROWBAND IMAGING: ADDITION BY SUBTRACTION 106

*The Spaces between the Notes* 108  
*Give Me Oxygen* 110  
*When a Star Hits Empty* 114  
*Fifty Shades of Red* 119  
*The "Hubble Palette" and Beyond* 119  
*Big Stars Go Bang* 129



9. A NIGHT IN THE LIFE: OBSERVING WITH THE  
WORLD'S LARGEST TELESCOPES 134

*These Are Professional Grade* 136

*Reservations Required?* 138

*Working Dusk till Dawn* 139

*Remote Control* 139

10. OUTSIDE THE RAINBOW: THE ELECTROMAGNETIC  
SPECTRUM, DIFFERENT KINDS OF LIGHT 146

*The Electromagnetic Spectrum* 146

*Radio, Radio* 151

*Microwaves: More Than the Oven* 151

*Infrared: Can You Feel the Heat?* 153

*Visible: The Tiny Slice You Can See* 156

*Ultraviolet: Light My Way* 156

*X-rays: Beyond the Dentist's Office* 158

*Gamma Rays: Light to the Extreme* 161

*The Invisible Made Visible* 162

11. PHOTOSHOPPING THE UNIVERSE: WHAT DO ASTRONOMERS  
DO? WHAT DO ASTRONOMERS NOT DO? 168

*From Data to an Image* 170

*Enter Photoshop* 171

*Cleaning the Image* 173

*What Not to Do* 175

12. THE AESTHETICS OF ASTROPHYSICS: PRINCIPLES OF  
COMPOSITION APPLIED TO THE UNIVERSE 180

*The Sharpness of an Image* 180

*Color Contrasts* 183

*The Composition of an Image* 189

*Structure and Detail* 199

*The Natural and Supernatural* 209

*Anatomy of an Image: Breakdown of the Pillars of Creation* 217

*Scientific and Beautiful* 219

EPILOGUE: SEEING THE EYE (AND HAND) OF GOD: PAREIDOLIA,  
OR SEEING FACES/OBJECTS IN ASTRONOMICAL IMAGERY 220

*Notes* 240

*Resources* 244

*Index* 246

COLORING THE UNIVERSE



## CHAPTER 1

# HUMAN VERSUS TELESCOPE

*Comparing Telescopic Vision with Human Vision*

## SEEING IS BELIEVING

Images of space can inspire awe and wonder. But in many urban and suburban spaces, the light from stars is mostly drowned out by the artificial glow (called **light pollution**) that humans have created. This is one reason that the pictures taken by telescopes on the highest mountaintops and remote deserts on Earth, as well as the armada of observatories in space, are so important. They are dramatic windows into our Universe.

The popularity of cosmic images is easy to spot. We see space pictures on computer screens and tablets, splashed on billboards, album covers, clothing, and everywhere in between. Despite our attraction and connection with space images, many people are not sure that what these images show is real. When one of our images was recently featured on a blog, several commenters were skeptical. “Really? Not Photoshopped? Amazing.” Another person commented in Spanish, “Me estas jodiendo, no puedo creer que no esté trucada.” (Rough translation: “Are you kidding me? I don’t believe this hasn’t been modified.”) Others express doubt that we can even see that far away.

► The iconic Horsehead Nebula is part of a dense cloud of gas in front of an active star-forming region known as IC 434. Credit: T. A. Rector (NOAO/AURA/NSF) and the Hubble Heritage Team (STScI/AURA/NASA).