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Adam M. Stuart, M.D.

With 201 figures, 142 in full color.

Springer

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My intellectual *past* was shaped by two visionary and brilliant giants of the twentieth century, the late Dr. Carl Sagan and Sir Arthur C. Clarke, who were instrumental in kindling a life-long interest in science and cultivating an appreciation for the greatest science fiction writing of all time. My greatest love, my children Lauren and Rachel, are my ambassadors to the *future* and are destined to be stellar in whatever they do.

Technical Innovations 6-ft (1.8-m) Home-Dome. Looking southwest in author's backyard. Royal Palm trees further west impede the view for the first 35° in altitude.

Preface

When I was a little boy I wanted to be an astronaut or a dinosaur hunter. I was 5 or 6 years old when I received my first telescope in the late 1960s, a 60-mm (2.4-in.) Tasco refractor. This white-and-black metal tube put me on a course to develop a life-long interest in astronomy, and science in general. I never became an astronaut (or a dinosaur hunter for that matter!), but I promised myself many years ago that when I got older and could afford some decent equipment, I would buy a telescope to rival that first 60-mm (2.4-in.) refractor.

Three short years ago I purchased a Meade 10-in. (25-cm) LX200 Schmidt-Cassegrain telescope. The Meade Telescope catalog had gorgeous images obtained with this telescope and a special camera: I had never heard of a CCD imager (charged-coupled device), but I knew I had to have one. A computerized GO TO telescope is not necessarily the suggested first "real" telescope to own, but I had my sights set on imaging and enough people in this wonderful hobby confided that Meade's was an adequate platform from which to image.

Did I mention that I live in Miami, Florida? Over the last 2 years, trading stories on the Internet, seeking advice and answers to my never-ending questions, I have learned that there is special recognition for those who image under the light-polluted skies of the world. Miami, like London, is right up there with some of the toughest skies under which to image. On the Bortle Scale, my imaging site rates an 8–9 on most nights (limiting magnitude 3 or 4: "most people don't look up"). Skyglow makes it difficult to collect data that are mired in the muck: Expose for too long and many astronomical targets of interest are barely discernible above the background "noise"; expose for too short an integration and the target of interest cannot register enough photons to adequately produce an image. My typical sky glows a hazy orange, extending a full 60° or more in some directions above my local horizon.

After a few weeks, the weight of my telescope and set up/break down time became a burden: I was at risk for joining the club of newcomers to this hobby who use their big, expensive telescopes as a living room ornament or as a hat rack after being in the field a few times with their equipment. A permanent set up in a fiberglass dome would be perfect! I dug a hole to China, bolted a steel pier to an isolated concrete pad, and assembled a fiberglass observatory on a concrete foundation to enclose everything. The purchase of my first CCD camera was my final ticket to entering the world of CCD astrophotography. Wiring the dome, a computer and the telescope for control from my house was a dream realized for a man whose first gaze upon our wonderful universe was through 60-mm (2.4-in.) of aperture, many moons ago. OakRidge Observatory saw first light September 1, 2002.

This book is a synopsis of my experiences, from the planning stages of building an observatory and making a laundry list of equipment and accessories, to finally obtaining and processing the various images contained in this book. I am humbled when I see the outstanding images obtained by my colleagues, many with less expensive equipment and portable set ups. Many readers of popular magazines such as *Sky & Telescope* and *Astronomy* might be left with the impression that high-quality images require a large telescope and dark skies. Not true! My determination in obtaining astrophotos under difficult imaging sky conditions has rewarded me with more than a degree of self-satisfaction. All those photons, teeming across space at mind-boggling speed for unimaginable eons, only to find my detector positioned just right to record the event. Few imagers have not heard people comment "Why take these photos of outer space? I can go online and find any picture I want!" This book cannot answer that question, but for those of us who have spent countless hours "doing what we love in the dark," each of us has a very personal reason for taking these images.

The inclusion of a few photos in both *Astronomy* and *Sky & Telescope* in 2004, as well as an invitation to submit two of my astrophotos to forthcoming astronomy publications, is flattering. Most recently, in September 2004 I was chosen as a Featured Observer in the ongoing Amateur Astronomy program at the Smithsonian National Air and Space Museum.

There are many people I need to thank. The many friendships that have been cultivated on the various Internet groups are a big part of the enjoyment that is derived from this hobby. The many brains that I have picked are numerous: There are some very knowledgeable, dedicated, and talented astroimagers out there, setting the bar higher and higher. I want to thank the publishers Harry Blom, Christopher Coughlin, and John Watson for their insightful discussions during manuscript preparation, as well as Lesley Poliner, Senior Production Editor at Springer.

Finally, my warmest appreciation goes to my wife Debi and daughters Lauren and Rachel: many, many nights have I said "I'm going into the dome," and what I got in return were smiles of encouragement. "Priceless."

Adam M. Stuart, M.D.
Miami, Florida
October 2004

Table of Contents

Introduction

Another CCD (charge-coupled device) imaging book? Bear with me as I explain why I think there will be support for yet another book on this topic. I have not seen a CCD imaging book written for beginners, by a beginner, documenting what can be captured under challenging skies. I own many books written by authoritative imagers, most all of which contain stunning photos taken under near-perfect conditions. If you are a beginner like me, you might be inspired and will strive to become better, or be intimidated and pursue another interest. I thought it would be instructive to publish my imaging experience because most of us with permanent imaging setups do not have the opportunity to throw our equipment into the car in search of pristine skies.

There are so many facets to this wonderful hobby of ours. Some of us love the beauty and mystery of the universe and do not own *any* astroimaging equipment. These people are content to view the work of others. Some of us have portable set ups; others have permanent imaging observatories. Some of us prefer to learn and enjoy astroimaging from the comfort of our favorite armchair, by reading books or magazines on the subject. Some of us prefer to return frequently to our favorite online websites, many of which whose owners have beautifully documented their journey in astroimaging. There are local astronomy clubs, planetariums, star parties, observing and imaging groups, and even astronomy imaging camps. You get the picture. Whether you are an absolute novice or a respected master of his craft, this hobby can be approached from many different directions if you delight in looking at images of the universe.

Be prepared to spend some money if you are interested in taking part in *gathering* those photons. Entry-level setups, ranging from portable telescopes with piggybacked 35-mm cameras, to gorgeous Ritchey-Chretien optical systems and professional-grade CCD cameras costing as much as a small house are available. Do your homework, take notes, and take note of your wallet before deciding on whether you are just putting a toe in the water or jumping in with both feet.

I was introduced to the gorgeous images of Jason Ware, Phillip Perkins, Jack Newton, Thierry Legault, Don Parker, and Ian King in Meade Instruments' 2000–2001 General Catalog and decided to wade into the water. I have never looked back. Our hobby is addictive and provides instant feedback as we watch our raw images download on a computer.

Finally, I am reminded that once in a while it is worthwhile to exchange the camera and CCD chip for an eyepiece. Time to "stop and smell the roses." When I am alone in my observatory and staring through an eyepiece at a distant target, or staring at a recently downloaded image on my computer monitor, you do not have to be spiritual to be moved by the grandeur of it all. The dimensions of our canvas are beyond comprehension. Who has not thought about the meaning of it all, beyond the pretty picture aspect?

CHAPTER ONE

The Challenge of Imaging Under a Light-Polluted Sky

Light pollution is the bane of amateur astronomers, whether your interest is in observing or imaging. Regardless of the quality of your local skies at your imaging site, the requirement to produce good charge-coupled device (CCD) images is the same. We want to maximize signal and minimize noise. This signal-to-noise ratio, known as S/N or SNR, is the holy grail of astroimagers. Signal (both good and bad) is the light that is recorded by the CCD chip, such as from a galaxy or globular star cluster, along with at least one type of unwanted light (skyglow). The exact unwanted signal cannot easily be known with certainty, but the goal is to separate out this unwanted signal.

Light pollution and other atmospheric factors contribute to the brightness of the sky background. Skyglow, one form of light pollution, is a key determinant in the ability to image extended, deep sky objects. The problem is that signal, both good and bad, builds linearly. If your mount is adequate and/or your imaging setup is equipped for guiding, extended integrations are possible. Unwanted skyglow, however, builds in tandem with your extended integrations. Image a galaxy for 30 s and your raw frame has both a dim galaxy image (hopefully, at least a dim image!) and possibly an overwhelming background glow. There are some extended objects that will be out of the reach of your CCD chip: Despite all of your best efforts and despite optimizing your system, skyglow will dominate your wanted signal, making your raw frames unusable. Solar system objects, such as the moon and bright planets, are not difficult CCD targets because integration times are short and wanted signal is easy to capture.

Sky brightness is measured in magnitudes per square arc-second. Because the brightness difference on the magnitude scale is a factor of 2.5 between each value, a magnitude 16 sky background requires 2.5 times longer integration time than when imaging under a magnitude 17 sky background, all other things being equal. If imaging a galaxy using 300-s integrations is achievable with your set up, a magnitude worsening of 1 in your sky brightness background now requires 750 s to image that same galaxy. Again, as mentioned earlier, some targets might need to be crossed off your wish list if longer integration times are prohibitive due to mount issues or due to background skyglow overwhelming wanted signal.

Fully two-thirds of Americans and Europeans can no longer discern our own Milky Way galaxy with the naked eye, and of the 2500 individual stars that should be visible under pristine, dark skies, closer to 200 stars are visible under a typical suburban sky (*Sky & Telescope* press release, October 11, 2002). "Take back the night sky" is a cry heard around the world by many of us who image under less-than-ideal, dark skies. Several states and European countries have enacted legislation to address wasteful light that ruins our night skies. The International Dark Sky Association (IDA), a nonprofit organization, has a website tool, DarkSky, that allows one to input their observing site coordinates (latitude and longitude, to four decimal places) and subsequently view the zenithal naked eye limiting magnitude. The limiting magnitude is only approximate and assumes perfect conditions, but the skies above my backyard observatory have a value of 3 to 5, depending on weather conditions and other factors. There are plenty of nights when the sky is cloudless, the humidity low, and the skyglow is similar to when we are near Full Moon.

All skies, even your favorite dark sky observing/imaging site, have a minimal background glow, produced from various sources. A typical suburban sky at night, however, is almost 5–10 times brighter at the zenith than the natural dark

Figure 1.1. Steve Albers has compiled an image of the United States that models light pollution. The Zenithal Limiting Magnitude for areas in red are less than 4.75 and is considered the worst on the scale. (Used with permission, Steve Albers, NOAA.)

sky. If you have had an opportunity to look skyward while walking down the streets of a populated city in the United Kingdom or in America, the sky is anything but dark, and the stars are anything but obvious in all directions. Inefficient lighting sources and particulate matter that is suspended in the air, such as smog and dust, contribute to this skyglow (see Figs. 1.1 and 1.2). Moisture in the air also contributes a bit. Many of us who have chosen to migrate to the suburbs, on

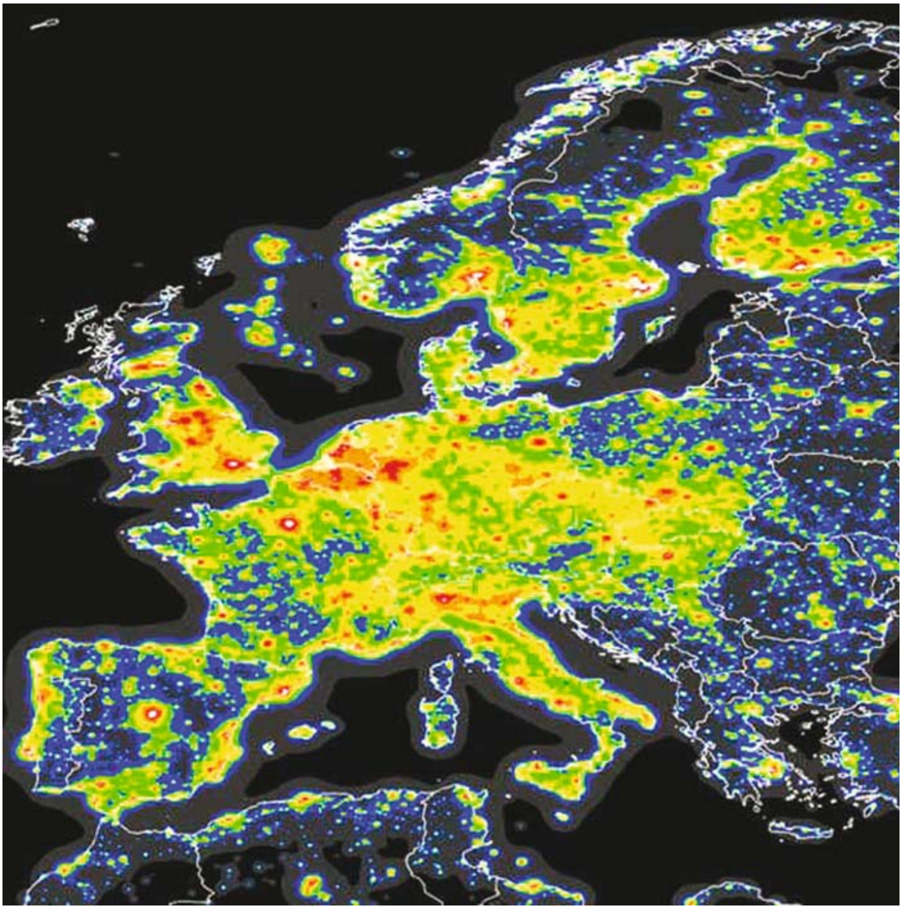

Figure 1.2. This map of Europe shows levels of light pollution in the atmosphere. The orange level indicates areas where the Milky Way is invisible; red areas indicate zones where approximately one-hundredth of stars are visible over 30° of elevation; blue borders indicate artificial sky brightness more than 10% that of the natural brightness, which is the definition of a "light-polluted sky." Yellow indicates an artificial sky brightness double that of the natural sky background. [Used with permission; Credit: P. Cinzano, F. Falchi (University of Padova), C. D. Elvidge (NOAA National Geophysical Data Center, Boulder). Copyright Royal Astronomical Society. Reproduced from the *Monthly Notices of the RAS* by permission of Blackwell Science.]

the outskirts of populated cities, live under a night sky that is likewise anything but dark. The orange glow that stretches from my local horizon upwards through 60+° in some directions is a combination of mall parking lights, unshielded or poorly aligned light fixtures, inefficient lamp sources, and security lighting that is unshielded. Mercury street lamps, outdoor sodium vapor lamps, and neon advertising signs limit the length of individual exposures that you can take. Without a compass, I can easily discern which direction downtown Miami is, almost 25 miles (42 km) distant, because the signature glow is strongest in one direction (see Fig. 1.3).

There are several ways to deal with artificial sky brightness. If you have a portable set up, nothing beats driving to a darker observing and imaging site. For those of us with permanent setups, there are several workarounds. Imaging late in the evening or early morning, when skyglow is diminished, is an effective but constraining solution for those of us who must work for a living. ("early to bed, early to rise" is the unfortunate mantra of many.) Imaging in a direction less affected by skyglow, because most skyglow is not uniform, or waiting for a target to climb higher in the sky and out of the glow are easy to accomplish. All successful imagers will agree that waiting for a target to approach its zenith, or transit, is the optimum time to image anyway. Select a target that you are interested in and use a planetarium software program (such as TheSky, Software Bisque) and time-

Figure 1.3. The orange glow of downtown Miami is unmistakable, looking North from the author's observatory. Polaris, the North star, is just visible in the original image.

skip the object until you find the transit time and date that meet your needs. The amount of atmosphere that you are imaging through is less the higher the object is in the sky. The reality is that although some targets never set and are always above the local horizon, they nevertheless hug the horizon, never getting above the glow. A few targets, such as M81 and M82, are bathed in an orange glow at my imaging location year-round. Imaging on dark (New Moon) and transparent nights, or when humidity is less, are further ways to combat skyglow. Direct glare, different than skyglow, can be blocked by erecting portable partitions to shield the telescope and camera from line-of-site intrusion.

Many astroimagers employ light-pollution-rejection filters in their imaging train. Meade, Celestron, Lumicon, and Hutech are a few of the many companies that manufacture these special filters. These glass filters have special coatings that reject sodium, incandescent, and mercury vapor, reflecting those wavelengths away from the CCD chip. There is no light amplification involved; the filter transmits the desired light of the object in which you are interested. Unfortunately, these filters do not work on all objects. Because the wavelength of starlight from galaxies and globular star clusters is similar to the rejected and unwanted light, imaging these targets with a light-pollution filter in the imaging train has diminishing returns. The goal of this filter is to transmit wanted signal

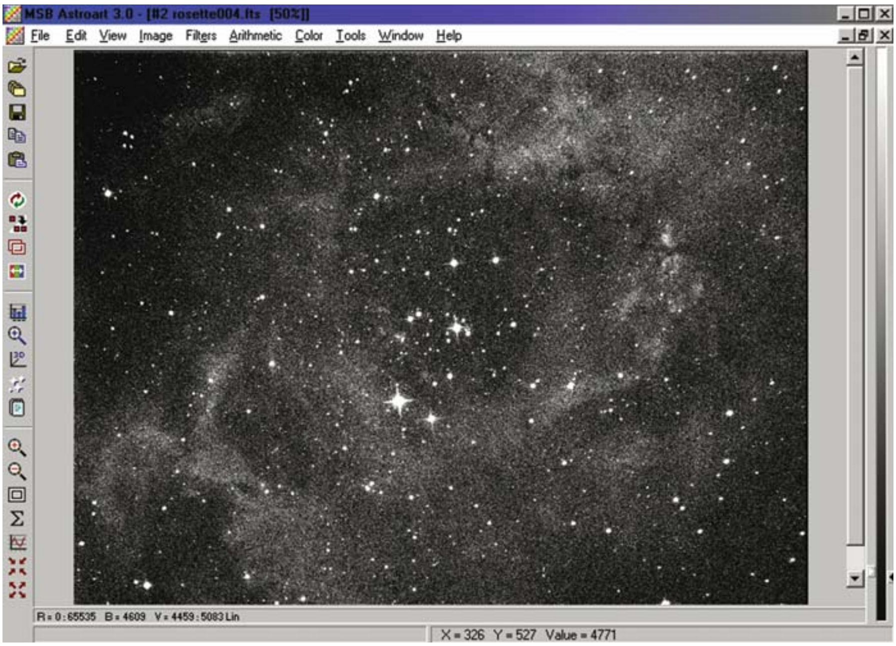

Figure 1.4. Astroart 3.0 screen capture. Single 300-s integration raw frame of the Rosette Nebula showing good nebulosity, captured with Astronomik 13-nm Ha filter. Diffraction spikes are artificial. Note the grainy background, indicative of noise, which can be removed with image processing. (Used with permission, MSB Software, Inc.)

and maintain proper color balance. Different manufacturers approach this issue differently, rejecting/transmitting light at slightly different wavelengths. The average price for a decent filter approximates the cost of a quality eyepiece. One downside to using a light-pollution filter is the requirement for longer integrations. Some of the blocked light is the desired light from the target you are imaging.

The luminous haze limits one's ability to see the stars and photograph what we see with our naked eye or through a lens. The extended deep sky objects that we cannot see, but that our favorite planetarium software shows us are there, are even more challenging to filter out of the mire. Light pollution adversely affects the ability of a CCD camera to record deep sky objects, but, fortunately, a CCD camera can integrate longer exposures to overcome light pollution to some extent.

Light pollution adds additional background signal to individual raw images, which must be subtracted out. Longer integration times on individual exposures (see Fig. 1.4) and taking more exposures in order to bring out the object of interest are further requirements. When you combine images, the SNR is improved because signal increases faster than noise. Signal increases in a linear fashion with

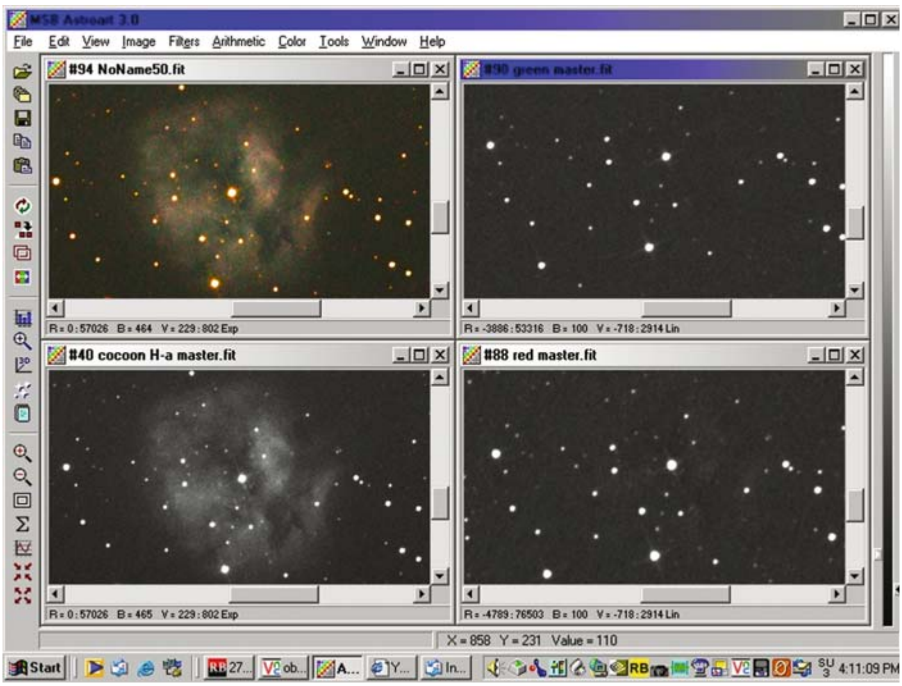

Figure 1.5. Astroart 3.0 screen capture. The Cocoon Nebula, even with 600-s integrations and an Ha filter, is still a dim target under my skies. The upper left panel shows a combined (Ha) RGB composite image. Representative channels show good signal in the Ha and barely discernible signal in the Red and Green channels. (Used with permission, MSB Software, Inc.)

each additional exposure, but noise increases as the square root of the number of images. Some imagers adjust their histograms by raising the black point high enough to hide any gradient that is present, but at the expense of losing faint detail in portions of the image. Light-pollution gradients should be dealt with first, allowing you to adjust the image histogram, which leaves a more pleasing display of the data. See Chapter IV, Processing Astrophotos Made Simple, for additional discussion about histograms.

If light pollution is severe or the object is too faint, the CCD chip will be saturated before a meaningful signal is recorded (see Fig 1.5). Additionally, light pollution is not uniform in images obtained with red, green, and blue (RGB) filters. If light pollution is not uniform, the resulting gradient must also be removed postprocessing.

Another possible work-around is to use a hydrogen alpha (Ha) filter. This type of filter is considered a narrow-bandpass filter due to selectively capturing the 656-nm Ha light that is emitted from emission nebulae. The filter allows this bandpass through and blocks most other light, including skyglow. High signal can be built with extended integrations. I use an Astronomik 13-nm Ha filter (Astronomik, Inc.) with a minimum of 300-s integrations (see Fig. 1.6).

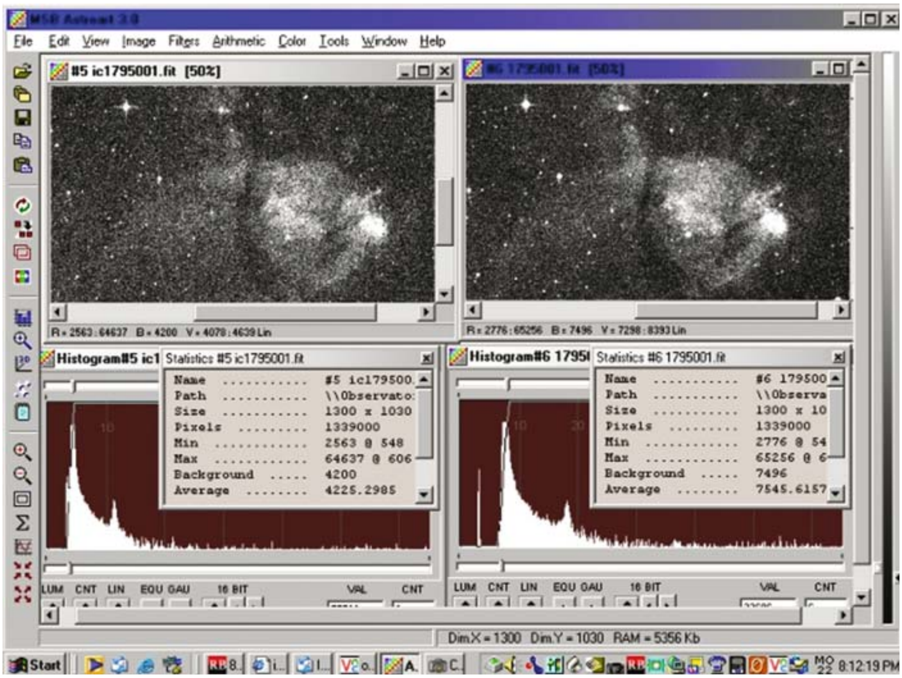

Figure 1.6. Astroart 3.0 screen capture. Emission Nebula IC1795 is shown as a raw, unstretched 600-s integration on the left and as a 900-s integration on the right. Five additional minutes yields less noise and more detail, as seen in the raw image. (Used with permission, MSB Software, Inc.)

CHAPTER TWO

Equipment Inventory

If boating on the ocean or on your local waterways is one of your hobbies, you might have heard the analogy that a person's boat is like a bottomless hole in the water: There is a never-ending list of must-have items and the hobby can be expensive. I was reminded that the universe, which is our bottomless hole, is likewise enormous and that I might need to hold my wallet tight and keep things in perspective as I assembled a list of "must-have" items.

A huge building with the word Tasco on it used to adorn the Miami skyline until a few years ago. Tasco has since purchased all of the major stock of Celestron International, and Tasco has since moved from the huge South Florida location, but whenever I drove past the building on State Route 826, I was gently nudged that I was "supposed to" buy that telescope that I always wanted. Tasco's product line was appealing to me as a child, when my needs were simple: visual observation, easy set up, an instrument with good optical quality. Celestron's and Meade's product line, however, both supported a higher performance for specialized use. When Meade's Telescope Catalog arrived in the mail in 2001, I was amazed at the size of some of the telescopes that amateur astronomers could purchase. It is a good thing that the catalog did not have any prices in it: I wanted the 16-in. (41-cm) Polar mounted LX200 at first sight!

Like most people who come to this hobby (or who come back to this hobby, as was my case), I thought magnification is king. The more obvious advertisements on most toy telescope boxes are that the optics will deliver 675× magnifications! We have all seen this type of advertisement. Most hobbyists will agree that a practical upper limit of magnification is 30–50× per inch of aperture. I quickly learned that it is the collection of light and a telescope's ability to resolve an image (how much detail can be observed through a given telescope), that are paramount. The larger the lens or mirror, the more light that can be collected, revealing brighter