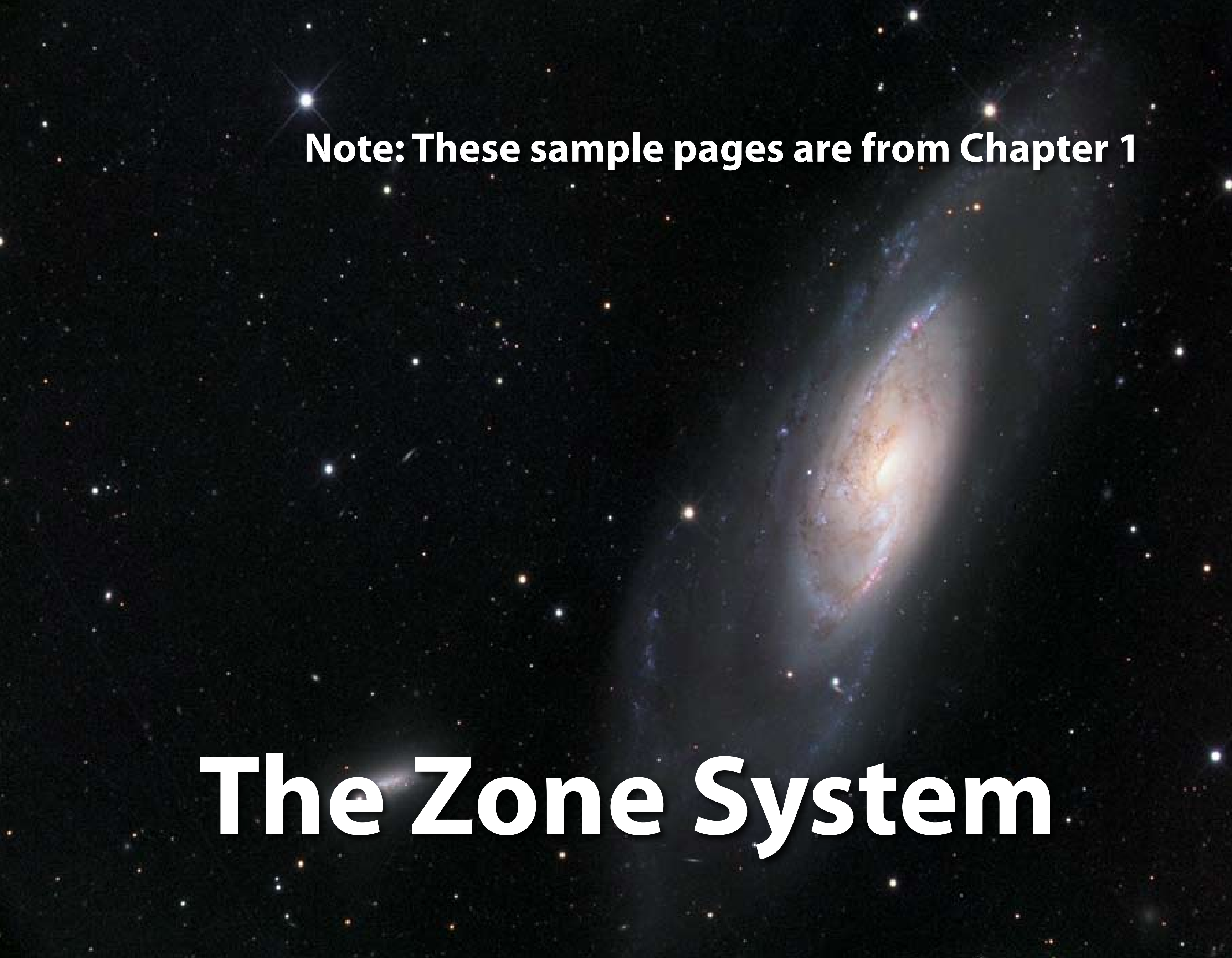
Note: These sample pages are from Chapter 1

The Zone System

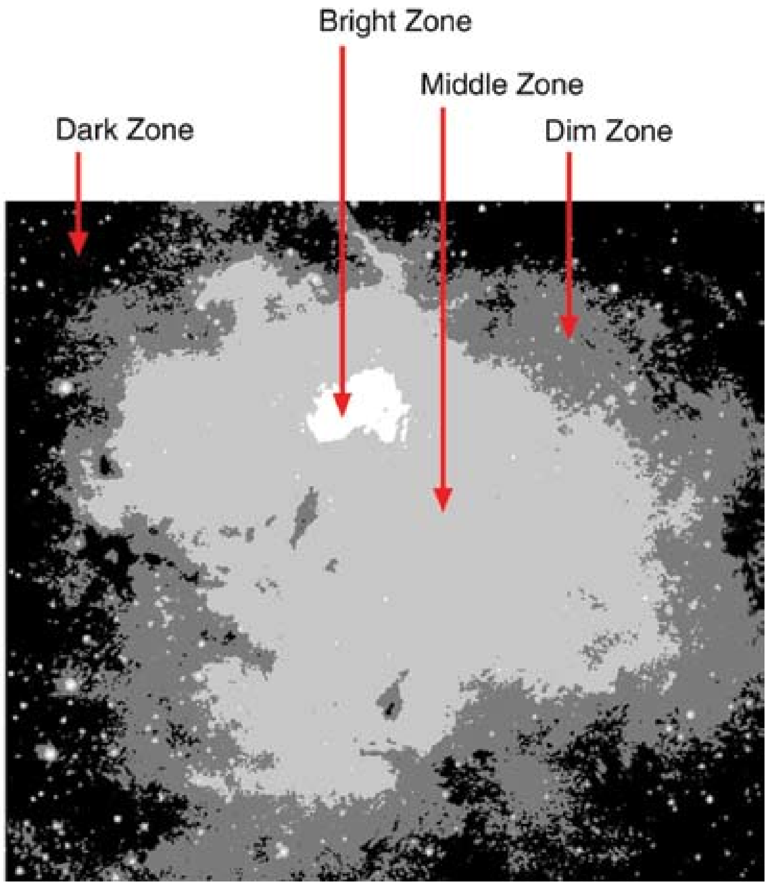


The Zones Revealed

The images below show how you can visualize the zones in an image. This is NGC 1491, an HII region imaged through a Hydrogen Alpha filter. The image at left shows the processed result using the Zone System. The image at right has been altered to show where the zones are located.

The proportion of the image in each zone depends on the length of exposure, and the total number of exposures. NGC 1491 is a dim object, so there is very little Bright Zone in the final image.

As is often the case, the Middle Zone dominates the image. Objects like the Lagoon Nebula, which has a large, broad area of bright nebulosity, will have a larger Bright Zone. Most objects are not as bright throughout, and they will have more Middle Zone than any other zone.



Signal to Noise Ratio

Zones are based on the signal to noise ratio in different parts of the image. A dim portion of the image has very little signal, while a bright area has a lot of signal.

The signal to noise ratio (abbreviated S/N), like any ratio, is simply one number divided by another. For example, if the signal is 1,000 and the noise is 25, then the S/N is simply 1,000 divided by 25 (1,000/25). To express this as a ratio, convention dictates that we use the colon, like this:

1,000:25

Further, convention tells us to make one side of the ratio expression unity (one). This is accomplished by dividing both sides of the expression by the lower number, 25 in this case. The result looks like this:

40:1

If the noise level were 25 across the image, then a bright area with a high signal (brightness level) of 30,000 will have a S/N of 1,200:1. A dim area with a low signal of 200 will have a S/N of 8:1.

Noise is not in fact constant across the image, and I will explain why a little later in this chapter (in the section Noise: Heart of the Zone System). Even so, the concept I want you to get is this: bright areas have high S/N, and dim areas have low S/N. This is important because:

- Areas with high S/N can be sharpened
- Areas with low S/N need smoothing

High S/N areas are typically things like galaxy cores, bright nebulosity, and of course longer exposures create better S/N values throughout the image.

Low S/N areas include such things as the image background, dim nebulosity, and the outer areas of a galaxy.

As you might have guessed, there is a very simple way to tell where the best S/N is in an image. The bright areas have the best S/N (as long as they are not saturated, of course).

For reasons explained later on, it is not simple to measure the amount of noise in an image. There are ways to estimate it, but fortunately there is a simple, trivial way to figure out where the best S/N is: brightness. That is why we use brightness to identify the zones in an image.

Different objects in an image can have different S/N ratios. For example, a widefield image of M81 and M82 includes galaxies with very different brightness levels. M82 is very bright and it is going to have the best S/N in the image. All but the core of M81 is much dimmer. You could easily wind up with each galaxy in a separate zone.

It's All About the Noise

Even though you can learn to estimate noise levels using brightness cues (and graininess helps, too), it's still important to understand what noise is and how it affects what you can do during image processing. I've included a complete section in this chapter that dives right into the facts about noise. Before we get technical, however, a little overview should help you get oriented.

Noise is something that most people would say they understand. This might be true when talking about, for example, the background noise at a party. But this is typically not true when we start looking closely at the mathematical realities of noise.

This might be easier to understand if we substitute new words for signal and noise. Try this:

Signal = Certainty

Noise = Uncertainty

In other words, instead of S/N, think in terms of:

Certainty/Uncertainty

Or, to put it in simplest terms:

Reality/Who Knows What

What does uncertainty (noise) do to an image? It makes the brightness values in the image variable. Suppose the variations are 25 brightness levels. Any brightness difference smaller than 25 brightness levels will be invisible in the image.

This uncertainty limits your processing choices. You can't sharpen an image to reveal details whose brightness difference is smaller than the noise level. (In fact, brightness details must be several times greater than the noise level to be visible.)

Uncertainty limits your processing choices. You would be wise to do anything you can to increase signal (certainty) and decrease noise (uncertainty) as you image and then process those images. S/N dictates your processing choices.

The image of M51 above has extremely low S/N, which means that brightness levels have large variability. So large, in fact, that even the spiral arms are barely discernible. This is one of my own very early images, and is just a few seconds of exposure time.

The image above, on the other hand, has superb S/N and reveals not only the presence of spiral arms, but an enormous amount of details within those arms.

Better S/N yields more certainty in the image, and it opens up processing options that will transform what you can do with your images.

The image below has been processed specifically to reveal details in the Dim Zone using two key techniques: the Standard Curve (see Chapter 2) and setting the boost for specific brightness levels (See Chapter 3).

With the Zone System, you can control individual zones and balance contrast between zones. In addition, you can separate sharpening from contrast changes. By breaking the image into zones, you gain control over every aspect of the image data.

Noise: Heart of the Zone System

If you understand what noise is, and how it affects your images, you have the keys to the Zone System.

Noise isn't so much a thing as a concept. In fact, preconceptions about noise can easily get in the way of getting a good grasp of the Zone System. Let's start at the very beginning, and build up a useful understanding of noise from scratch.

Engrave this somewhere in your memory banks:

Noise is the uncertainty in the data.

That's right—noise isn't a thing, nor is it easily measurable. Noise consists of random variations in the brightness levels of an image. For example, suppose that we image a blank wall that has a true brightness value of 100. Suppose further that we have some simple device that allows us to take measurements of the brightness of that wall. Noise will result in values that cluster around the true value—98, 95, 102, 110, 93, and so on. The variations are random, and no one measurement will give us the true value of the brightness of the wall. Each measurement will vary from the truth by some amount. These variations are noise.

Where does the noise come from in a CCD image? It comes from a variety of sources. The most significant sources are **read noise** and **shot noise.** (More about these in a moment.)

A CCD chip works by converting incoming photons into electrons. At the end of an exposure, the electrons in each pixel are counted, and sent to your computer.

Read noise occurs when the CCD chip doesn't count the number of electrons accurately. Electrons are counted in a special pixel on the CCD chip. Some electrons might "stick" to the pixel and not get read. Some electrons might sneak in during the counting process. By whatever means, read noise results in random variations from pixel to pixel as the data is being read from the chip.

The amount of read noise is the number of electrons by which the read operation can vary from the true value. This does not mean that the read operation will be off by that value every time. If the read noise is, say, ±10 electrons at 0° C, then for each pixel the uncertainty (noise) will be a total of 20 electrons. Any given pixel might be off by zero, –5, 9, etc.

Note the presence of a temperature in that description. The colder a CCD chip is, the lower the overall noise will be. This is why most CCD chips in astronomical cameras are cooled.

Shot noise, also called photon noise, results from the quantum nature of light. In other words, light itself is noisy. Shot noise follows a very simple rule: the noise (uncertainty) is equal to the square root of the signal. So if the brightness level is 100, the shot noise is 10.

Noise Control

An analysis of the two types of noise demonstrates a key fact. The uncertainty of the read operation is the same no matter how bright the image is. That is, a longer exposure has the same read noise as a short exposure. However, the uncertainty of the shot noise increases with exposure time. (Fortunately, the signal increases at a faster rate than the noise. The S/N of shot noise always gets better with longer exposures.)

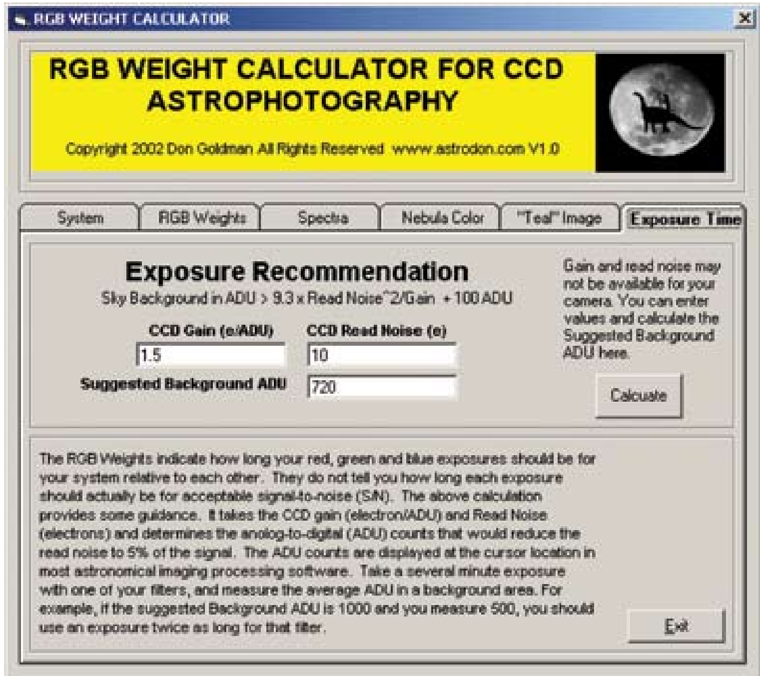
This leads to a simple strategy for controlling noise. If the exposure is long enough, the shot noise will dominate, nearly eliminating read noise as a factor. In other words, the total noise in the image will be nearly equal to the square root of the signal level. (If read noise is 10, and shot noise is 1,000, then the read noise is only 1% of the total noise. It becomes a non-factor.)

Because different CCD chips have different levels of read noise, there isn't a single exposure time that will yield a shot noise high enough to obscure the read noise. In addition, the brightness of the sky plays a large role in the shot noise. The brighter your sky, the more rapidly the shot noise will cover the read noise. This sounds good, but think of the penalty here: a brighter sky is a noisier sky. That is why dark skies are so desirable for astronomical imaging.

Shot noise from background brightness will be lower at a dark-sky site, but the contribution of read noise will be proportionally higher. So longer exposures are the norm for dark sites, and shorter exposures for bright sites.

The goal then is an exposure long enough to swamp the read noise with the shot noise. That exposure length depends on the shot noise at your imaging location.

The most useful way to determine the minimum exposure time is with the image background brightness. For a given sensor and location, a certain exposure length optimizes the read noise/shot noise ratio.



Stan Moore has web pages dedicated to calculating the optimal background level:

http://home.earthlink.net/~stanleymm/CCD_topics.html

Don Goldman's RGB Weight Calculator includes Stan's calculations (see above) along with other very useful tools:

http://www.astrodon.com

CCDWare has a web page dedicated to determining the optimum exposure time for your site:

http://www.ccdware.com/resources/subexposure.cfm

The Dark Zone

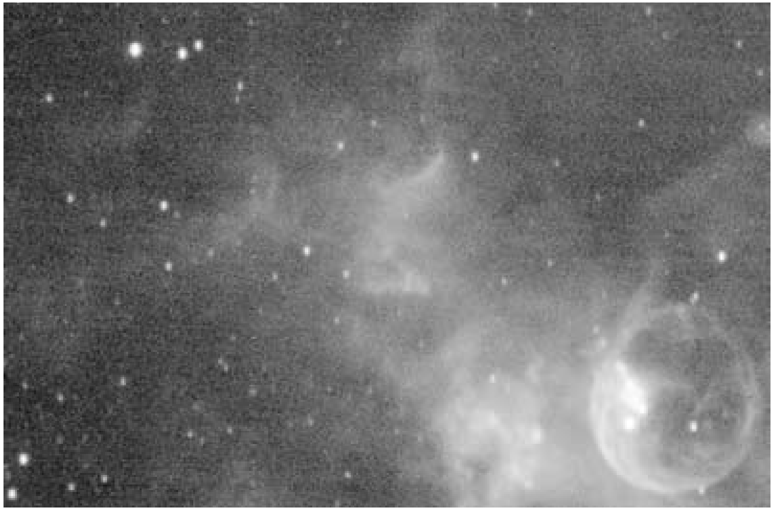
The Dark Zone is that portion of the image that is so dominated by noise that it is useless for presentation in the final image.

Put in simplest terms, the Dark Zone is the lost portion of the image. It's a throwaway. Use the black point to get rid of the Dark Zone completely. By raising the black point until the Dark Zone is hidden, you will dramatically improve the appearance of an image.

The image at left below shows what lurks in the Dark Zone: horrendous noise. There is horizontal streaking from excessive read noise, and there is lots of random noise as well. The exact nature of the noise you'll find in the Dark Zone will vary from one camera to the next, but the overall result will be similar to what you see here. That's why the Dark Zone has to go. Raising the black point takes care of the problem, as shown at lower right.

You won't always be able to simply raise the black point to the precise correct level in one try. If the exposure time is short, it is easy to go too far with the black point. I usually work on the black point several times while processing an image, getting it closer to the ideal point as the image processing reveals more of the dim details in the image.

You should use the image histogram to guide you in placing the black point, as shown in chapter 2, ***Photoshop® Basics: The Standard Curve.***



Noise is present throughout an image, but it shows up most clearly in the Dark Zone because there is little signal in the Dark Zone. In other words, the signal to noise ratio (S/N) is very poor in the Dark Zone.

Anything you do to reduce noise will push the Dark Zone down further, giving you more dim details in your images.

✾ TIP: Longer exposure times push areas of the image up the zone scale. Dim moves to Middle, Middle moves to Bright.

Here are some techniques that will lower your noise levels:

- Long total exposure time. Think in terms of hours, not minutes.
- Long enough individual exposures to minimize the contribution of read noise. See earlier sections of this chapter for web links for determining this exposure time.
- Dark skies. Not much you can do about this when you image from the typical back yard, but if you can get out to a dark site you'll see significant benefits.
- Sharp focus. Even a slight mis-focus will spread out the light and reduce contrast and detail in the image. This reduces the signal level, and makes noise more prominent. Yes, that means you can attack the noise problem in two ways: by reducing noise, and increasing signal.
- Careful image calibration/reduction, using large numbers of bias, dark and flat fields. See chapter 4 for more information about calibration and reduction.

Why Is Noise Grainy?

The above question illustrates a common misconception about noise. You probably think about noise like this: "The noisiest parts of the image are obvious because they show the most grain." This is not correct because the noise level in the image is constant. It is the signal level that changes across the image. The correct description is: "The most signal-deprived areas of the image are obvious because they show the most grain."

For example, assume that the noise level is 10. Let's compare two areas of the image with different signal levels. One area has a signal level of 100, with a signal to noise ratio (S/N) of 10:1. The other area has a signal level of 1,000 for a S/N of 100:1.

In the area with S/N of 10:1, the individual pixels vary by up to 10% of the signal level. It is easy to see this level of individual variation because the random variations in pixel brightness are a significant percentage of the signal level. Low S/N is typical of the Dark and Dim zones of an image, and the large relative differences from pixel to pixel make these zones look grainy.

In the area with S/N of 100:1, the individual pixels vary by no more than 1% of the signal level. The eye can't distinguish such small variations, and the area appears much less noisy, perhaps even noise free. The random variations are such a small percentage of the signal level that the eye can't see the differences very well.

The Dim Zone

The Dim Zone is the noisy but salvageable portion of the image.

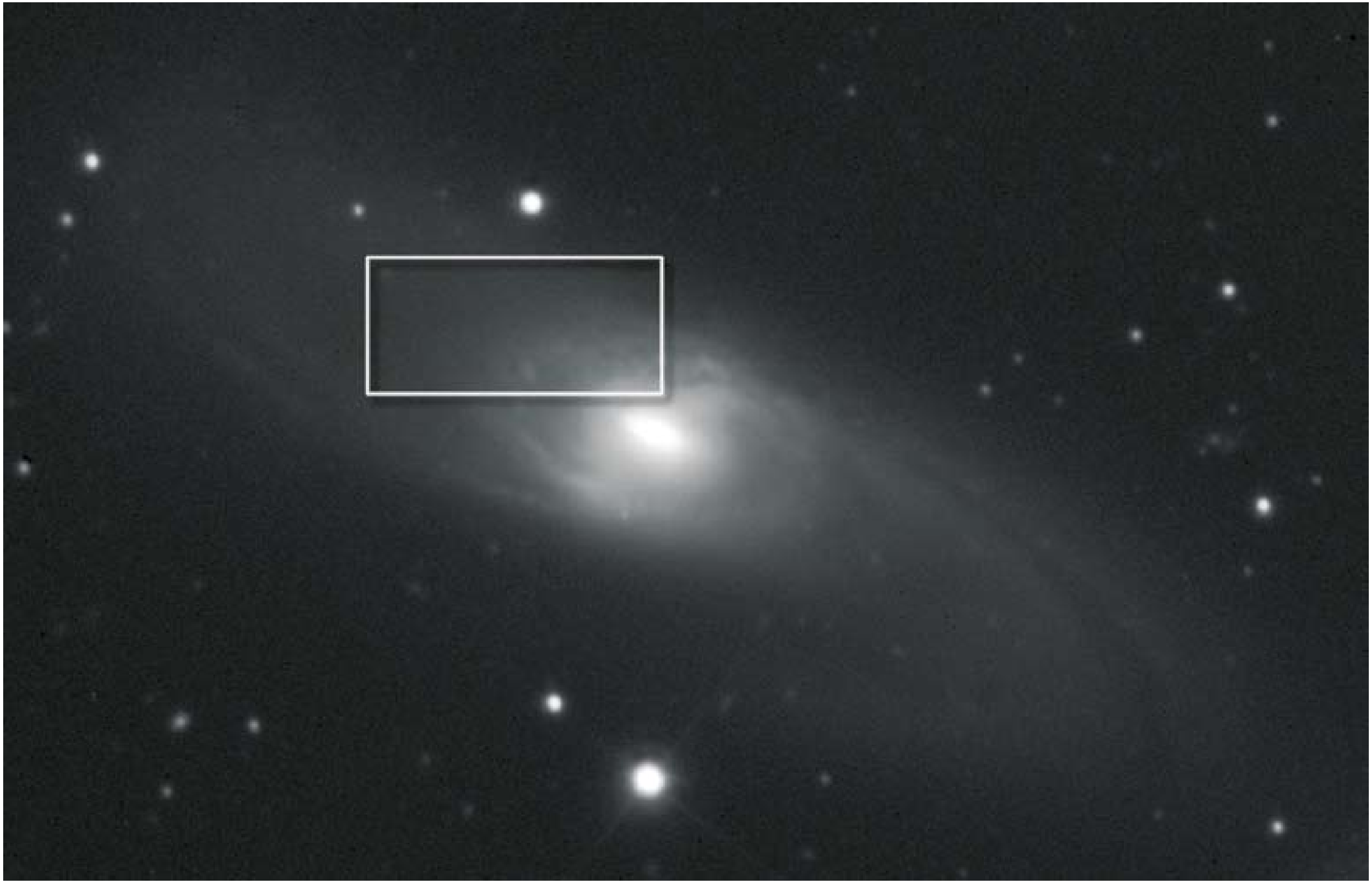
The Dim Zone is noisy, but not so noisy that it needs to be gotten rid of. With a little smoothing and blurring, the Dim Zone can be made to look quite respectable.

Despite the presence of noise in the Dim Zone, the eye can perceive at least some details. The details are typically obscured by noise. Details that have strong enough contrast to rise above the noise will be visible, but more subtle details, with minimal contrast, do not rise above the noise levels.

The irony with the Dim Zone is that in many images it contains the most interesting information. Dim nebulosity, the outer areas of galaxies—all of these are full of interesting details. Long exposures will bring out the most in the dim areas, but careful Dim Zone processing will reveal as much detail as is present in the data. Without proper Dim Zone processing, details might get lost and never be revealed.

This leads to a simple fact that has led many an image processor to frustration: the Dim Zone is the hardest zone to process, yet it contains the most desired details. Careful application of smoothing, followed by careful Zone System processing, will save the day.

The figures above are details from a larger image (see next page) that show before and after processing for the Dim Zone. The top image is the raw original. The bottom image shows the appearance of this area after smoothing. See chapter 3 for details on applying smoothing to the Dim Zone of an image.



The image of NGC 5566 above is a raw image without smoothing. The lower right corner of the box was used for the smoothing example on the previous page. Most of the area included in the box is part of the image's Dim Zone.

The Middle Zone

The portion of the image between the Dim and Bright Zones.

The above definition seems like a cop-out, but there just isn't a better one available. The Dim Zone is well defined by dominant noise; the Bright Zone is well defined by extremely low noise. The Middle Zone is simply the stuff between those two extremes.

In fact, you can make a good case for a continuum including the Dim, Middle, and Bright Zone. The boundaries between Dim/Middle and Middle/Bright are fuzzy at best. The darker portion of the Middle Zone needs some of the same processing as the Dim Zone, just less of it. Likewise, the lighter portions of the Middle Zone can use a bit of the same type of processing as the Bright Zone.

In a sense, you could say that the Middle Zone can be divided into three sub-zones: Dim–Middle, Middle–Middle, and Bright–Middle. As you gain more skill with processing using Zones, such distinctions allow you to fine-tune your techniques.

The bottom line for the Middle Zone is that it's not noisy enough to need much smoothing, and S/N isn't good enough to encourage sharpening. The bulk of the processing for the Middle Zone is the histogram changes that are used to bring out dim details. See chapter 2, ***Photoshop® Basics: The Standard Curve,*** for an example of histogram processing.

The above example shows an extreme case of an image that consists only of Dim and Middle Zones. This is a small portion of the Pelican Nebula. Consisting of a single exposure, it just doesn't have a Bright Zone. (To be technically correct, it does have a Bright Zone—the stars. But what we really want is to have some of the nebula in the Bright Zone!) Smoothing salvaged the image, and even though it's somewhat dark, it's still an interesting result.

The Bright Zone

The Bright Zone contains the areas of the image with the best signal to noise ratio.

The Bright Zone is the easiest portion of the image to work with. Noise is extremely low compared to the signal, and you typically can't even detect the noise at all, at least not visually.

The Bright Zone is your prime area for sharpening, but you'll need to be careful not to overdo it. The right amount of sharpening will reveal details that were hidden prior to sharpening. If you over-sharpen, however, you'll create artifacts instead of revealing details. Keep an eye on the image, and use your knowledge of the object, to determine how much sharpening to use. The stronger the signal in the Bright Zone, the less likely you are to generate artifacts.

The two most common sharpening methods are deconvolution and unsharp masking. Photoshop® does not include deconvolution tools, but most CCD control programs include one or more deconvolution methods. These include MaxIm DL, CCDSoft, CCDSharp, Astroart, and many others. The exact features vary from version to version, however.

Many of these programs also include good tools for unsharp masking. Photoshop® supports unsharp masking as well, and you'll find some useful and innovative advice in chapter 3.

NOTE: Each type of sharpening has characteristic types of artifacts that you'll need to watch out for, and this is covered in the various chapters on sharpening.

You can also use unsharp masking outside of the Bright Zone using large-feature sharpening (also covered in chapter 3). Normally, the noise in the Middle and Dim Zones results in excessive artifacts rather than useful sharpening. By raising the Threshold setting, you can apply sharpening safely to zones that normally would not benefit from sharpening.

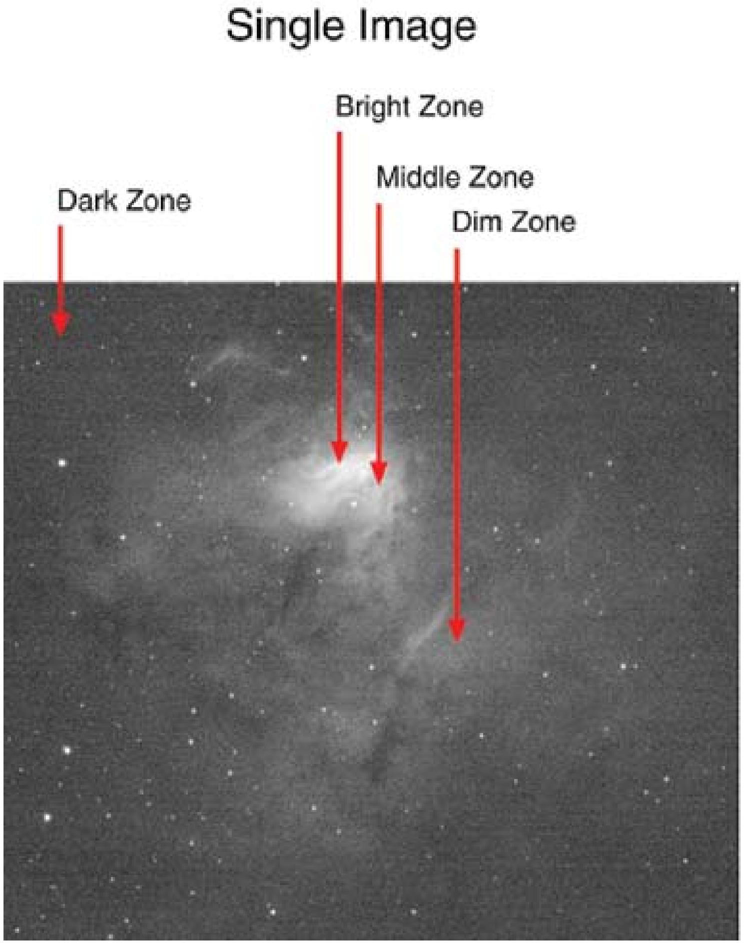
The ideal image would have lots of area in the Bright Zone. There is a very simple rule you can follow to put as much of the image as possible into the Bright Zone:

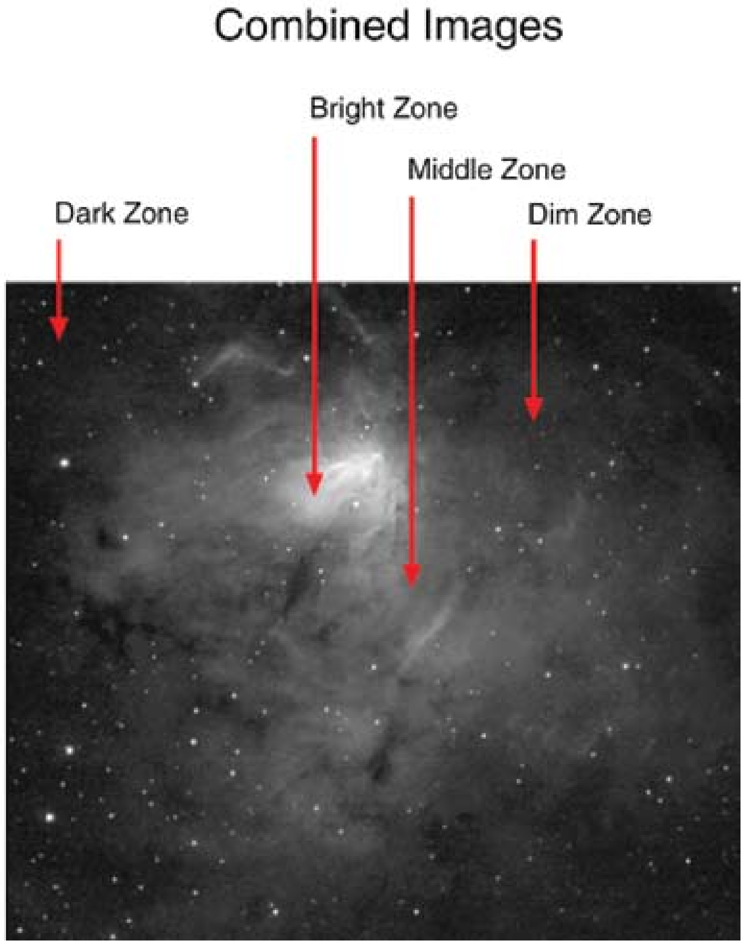
You can increase the portion of the image in the Bright Zone by using a longer total exposure time.

That sounds simple, and it is simple. The longer you expose, the easier your image will be to process. When I am teaching classes on image processing, students frequently ask me what is the one thing they can do to improve their image processing. My answer: take longer exposures. The Dim Zone is the toughest part of the image to process. The Middle Zone is better, and the Bright Zone is practically a slam dunk. By taking longer exposures, you solve most of the image processing problems before you even start your processing.

Even an object with very little bright content benefits from longer total exposure time. Moving parts of the image from the Dim Zone to the Middle Zone is worthwhile because you will often image objects that just don't have that much brightness to start with. It is *relative* brightness, not absolute brightness, that determines the zones!

The figures on the facing page show the value of combining multiple exposures to get a long total exposure time.


Single Image
Bright Zone
Middle Zone
Dark Zone
Dim Zone


Combined Images
Bright Zone
Middle Zone
Dark Zone
Dim Zone

This image of M95 shows good zone control. The noise of the Dark and Dim Zones is not evident because the black point has been set appropriately. The details in the Bright Zone are clearly and carefully revealed. In particular, the details in the unusual core of the galaxy are visible. The Middle Zone details are not sharpened very much, but they are clear and show little evidence of noise.