Sub-Exposure Times and Signal-to-Noise Considerations
An Application Note

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Introduction

Some analytical papers have been written presenting the trade-offs for shorter sub-exposures. The purpose of this note is to provide some examples of the application of the conclusions in this paper. It is hoped that these examples will serve to make concrete the concepts in these papers.

Examples

Let's assume that we have measured our background sky flux using the technique identified previously. We have chosen to allow the readout noise contribution to be 5% of the total noise contributed by the background sky. That exposure time has been calculated to be 10 minutes. Let us further assume for our experiment that we plan to take 40 minutes total exposure time.

First, how much loss of SNR do we suffer by using shorter exposures?

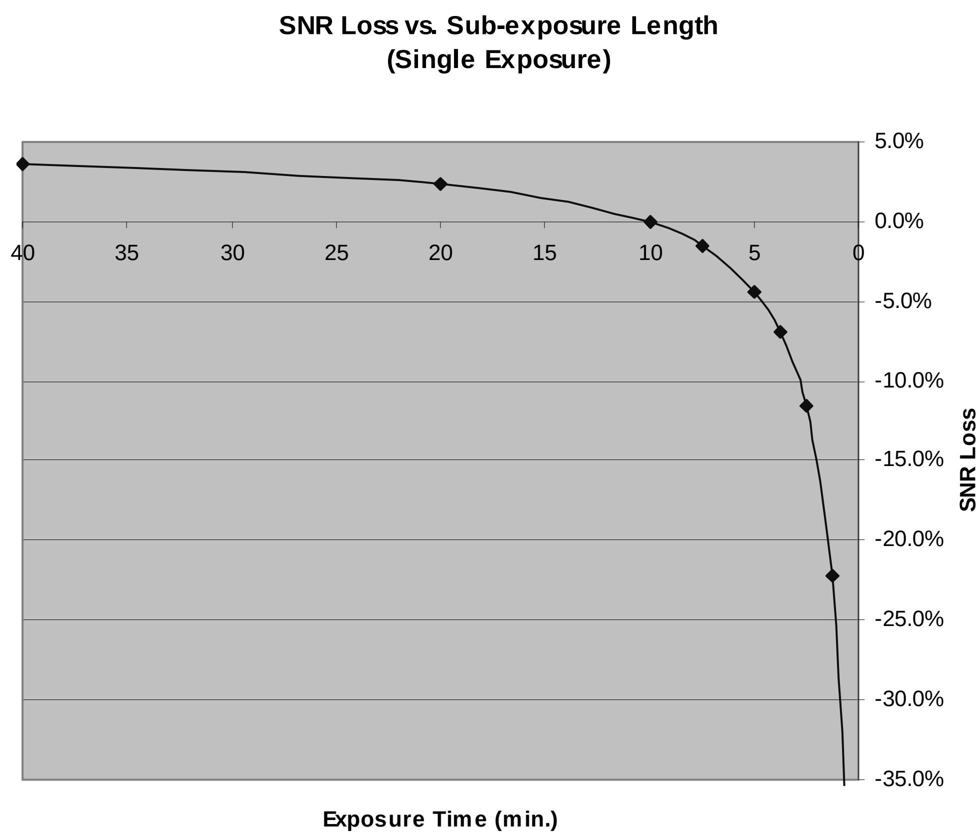

Figure 1: SNR Loss

Shorter exposures are to the right. We can see a single 5 minute exposure will suffer a SNR loss of 4.3% and a single 3.75 minute exposure will suffer a SNR loss of 6.9%. Also a 20 minute exposure will achieve a modest SNR *gain* of 2.4% and a 40 minute exposure will achieve a gain of 3.7%.

Clearly for single exposures, the best reduction in random noise is achieved by longer and longer single exposures. Unfortunately, we have more than random noise to contend with. We have cosmic rays, satellites, airplanes and other potential problems that could damage our image. And of course, the longer we expose, the higher the probability of those events. Also, the longer we expose, the higher the likelihood of saturated stars and blooms.

Fortunately, we do not rely on a single long exposure but routinely stack exposures. So let's look at how many more shorter exposures are required to maintain the 10 minute SNR. For this example, we will assume stacking 4 – 10 minute exposures for a total exposure time of 40 minutes. I have used the results of the paper to calculate the number of sub-exposures required and rounded the number of exposures up to the next highest integer, since we generally use equal-length sub-exposures.

So, how long must our total exposure time be to achieve the same SNR as our 4 – 10 minute exposures?

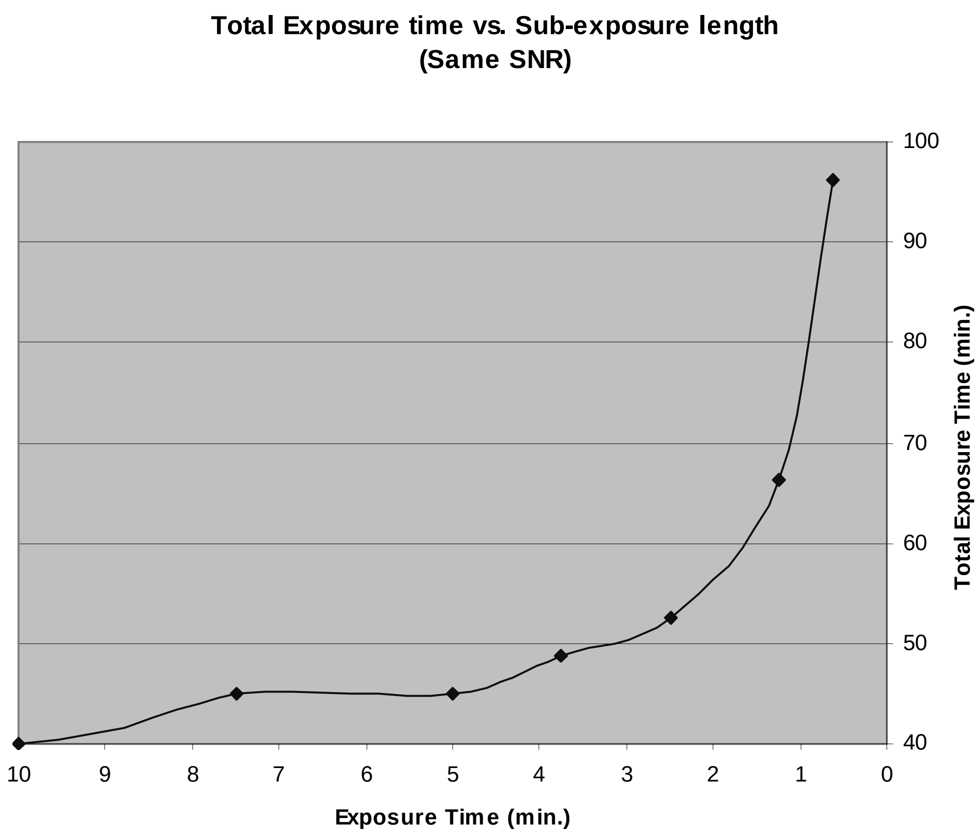

Figure 2: Total Exposure Time

What this indicates is that we must expose for 45 minutes with our 5 minute sub-exposures and for almost 49 minutes for our 3.75 minute sub-exposures to achieve the same SNR. We can also note that shorter and shorter exposures have a higher and higher time penalty to achieve the same SNR. The point of diminishing returns is pretty apparent from Figure 2. But, there is a “sweet spot” that we can take use to our advantage and that is between 5 and 3 minutes, i.e. between ½ and 1/3 of the “overwhelm read noise” exposure time.

With shorter exposures, we can better eliminate non-random artifacts. If we have a sufficient number of sub-exposures, we can discard one with minimal loss of SNR and by having more samples we can use outlier rejection combining, such as Sigma and others to minimize or even eliminate their visibility. These combining choices are less effective with lower number of frames. Additionally, if dithering is used along with these combining approaches, hot pixels, pattern noise and other imperfections of CCD chips can be mitigated.

(Dithering consists of slightly moving where the camera is pointed from frame to frame. This can be accomplished by either moving the guider coordinates for guided imaging or moving the telescope itself for unguided imaging. When the sub-exposures are registered, the chip imperfections don’t appear in the same location. When the aligned sub-exposures are subsequently combined, the imperfections are rejected as outliers.)

So, from the above examples, we would get 4 frames of 10 minutes, 9 frames of 5 minutes and 19 frames of 3.75 minutes. The latter two give us more data points per (aligned) pixel to work with to remove artifacts and a single satellite trail is easily removed by not using the offending frame.

The costs for this approach are more files to deal with, longer exposure time and increased download and, if used, guider acquisition time. How much does this add?

With my ST-10XME and AO7, I have a download time of 17 sec. If I dither the images using my Sequencer program, it takes around 10 sec. to move and reacquire the guide star. In this case, I am using reasonable AO7 track times of 0.5 sec. For the 5 minute exposure case, I need 1 additional 5 minute exposure frame and 5 times (10 + 17) sec. for a total increased time of 7.25 minutes. For the 3.75 minute case, I need 3 additional frames and 9 times (10 + 17) sec. for a total increased time of 15.3 minutes. This additional time expenditure allows less costly removal of non-random noise rejection and, if dithering is used, a reduction of CCD chip artifacts.

Beyond a reduction of 3, i.e., sub-exposure times of less than 3.3 minutes in this example, the cost in total time begins to outweigh the benefit of more samples.

However, one thing to consider is if you are imaging a bright object like M20. There are some very bright stars in the center of the object and the emission and reflection nebulosity is reasonably bright. In that case, we move to the bright object case as discussed in the paper and many short exposures make sense to preserve star colors and minimize blooms.

Concluding Thoughts

The above example assumes 10 minutes is the reference exposure, as calculated using the method in the first reference. Your specific situation may differ and you should scale the 10 minute number to your sky glow conditions. The key point is there is a "sweet spot" where your sub-exposure is ½ to 1/3 of your overwhelm read noise exposure time that will better enable you to deal with more types of noise.

I hope this will make concrete the advantages and trade-offs of using shorter sub-exposures. With the modern computers we use today, additional data frames pose a minimal burden either in hard disk storage or processing and the resultant image quality benefits are significant. There is a certain sense of freedom in discarding an image with a satellite trail, knowing it will have minimal impact on your overall image's SNR. With dithering, you will enjoy much better hot pixel removal than any hot pixel filter can ever achieve, when coupled with outlier rejection combine algorithms.

References

http://www.hiddenloft.com/notes/SubExposures.pdf
http://www.hiddenloft.com/notes/dithering.htm