DEADTIME

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Abstract

The concept of deadtime in pulse-counting photometry is discussed, and a method for measuring it is given. It is shown that a large error may result for bright stars if the deadtime correction is not applied.

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Amateur astronomers trying to reduce photoelectric data taken with a pulse counting system may find that the brightest stars observed yield magnitudes in serious disagreement with accepted values. These bright stars are so bright that the counter fails to count all the incoming photons. To correct for this error, we can use the concept of deadtime: the period of time it takes the counter to recover after detecting a photon; during this time no other photons can be counted.

Photon counters can be divided into two types: nonparalyzable and paralyzable. Suppose a photon arrives at a time t_o and is followed by a second photon at $t_o + \tau$, where τ is less than the deadtime δ. The second photon is not counted by either type of counter. The nonparalyzable counter is not even affected by the second photon, and at times $t_o + \delta$ it regains its counting ability. The paralyzable counter, however, is affected by the second photon: its dead period is prolonged to time $t_o + \tau + \delta$.

How does one know whether his counter is paralyzable or nonparalyzable? Most people have no idea of whether their counters fit into one of these two ideal categories or exhibit behavior somewhere in between. Fortunately, it doesn't usually matter. It can be shown mathematically that the deadtime-corrected count of the paralyzable counter is very nearly equal to that of the nonparalyzable counter when the counting rate is not excessively high.

For the nonparalyzable system, we can easily derive a formula giving the true number of photons in terms of the number observed and the deadtime. We assume the photon arrival times are completely random. Suppose that in a 1-second period our counter registered n photons. Then we know that the counter was dead for n periods, each δ in duration. The total dead period was $n\delta$, so the counter was, in effect, on for only $(1-n\delta)$ seconds. Suppose the true photon arrival rate was N photons/sec. Then multiplying N by the effective on time, $1-n\delta$, should give us the observed counting rate:

$$n = N(1-n\delta) \qquad (1)$$

or

$$N = \frac{n}{(1-n\delta)} \qquad (2)$$

Measuring a counter's deadtime is surprisingly simple. One need only have: (1) two apertures which differ significantly in size, and (2) some filters. First, look at the daylight sky with a filter which gives a counting rate n_s through the small aperture greater than 20 times the dark count. Then, switch to the large aperture -- with the same filter -- and measure the counting rate

n_ℓ. Now, change the filter to one that gives a counting rate, n_s', through the small aperture greater than 10 times n_s. Finally, use the large aperture and the new filter to measure the counting rate n_ℓ'. The ratio of the apertures is constant and equal to the ratio of true counts (with the same filter). Making the deadtime correction for each measurement, using equation (2), this ratio is:

$$\frac{n_s}{1-n_s\delta} \times \frac{1-n_\ell\delta}{n_\ell} = \frac{n_s'}{1-n_s'\delta} \times \frac{1-n_\ell'\delta}{n_\ell'} = \text{Ratio of apertures} \quad (3)$$

Equation 3 can be solved for δ, giving:

$$\delta = \frac{n_s n_\ell' - n_\ell n_s'}{n_s n_\ell (n_\ell' - n_s') + n_s' n_\ell' (n_s - n_\ell)} \quad (4)$$

Once the deadtime for a given counter is known, correction to the observed counting rates of stars can be made routinely using equation (2). Figure 1 is a plot of N vs n for various deadtimes. Figure 2 is a plot which gives the percent error which would result from neglecting the deadtime correction. (From equation (2) you can show that this percent error is just equal to 100 $n\delta$). Figure 2 also gives the error in measured magnitude which would result from ignoring the deadtime correction.

Deadtime corrections are most important when measuring bright stars. For example, consider a 10th magnitude star which gives an observed counting rate of 10,000/sec, and suppose the deadtime is 3×10^{-8} sec. Then, the corrected rate is found to be 10,003/sec. The error is .03%, giving a magnitude .0003 too large. Clearly other errors will completely swamp this, so the correction for the deadtime, in this case, can be ignored. For a 7th magnitude star the observed count would be about 158,000/sec and the corrected rate 158,752/sec. The error is now .5%, giving a magnitude .005 too large, again, in most cases, insignificant. Finally, for a 2nd magnitude star the observed counting rate would be on the order of 11,000,000/sec, whereas the corrected rate would be 16,400,000/sec, so the error is 33%. The error in stellar magnitude would be about $0^m_.43$.

It can be seen that the deadtime correction is very important for observers observing the very brightest of objects. For those doing photometry on relatively dim objects, the deadtime correction can probably be ignored.

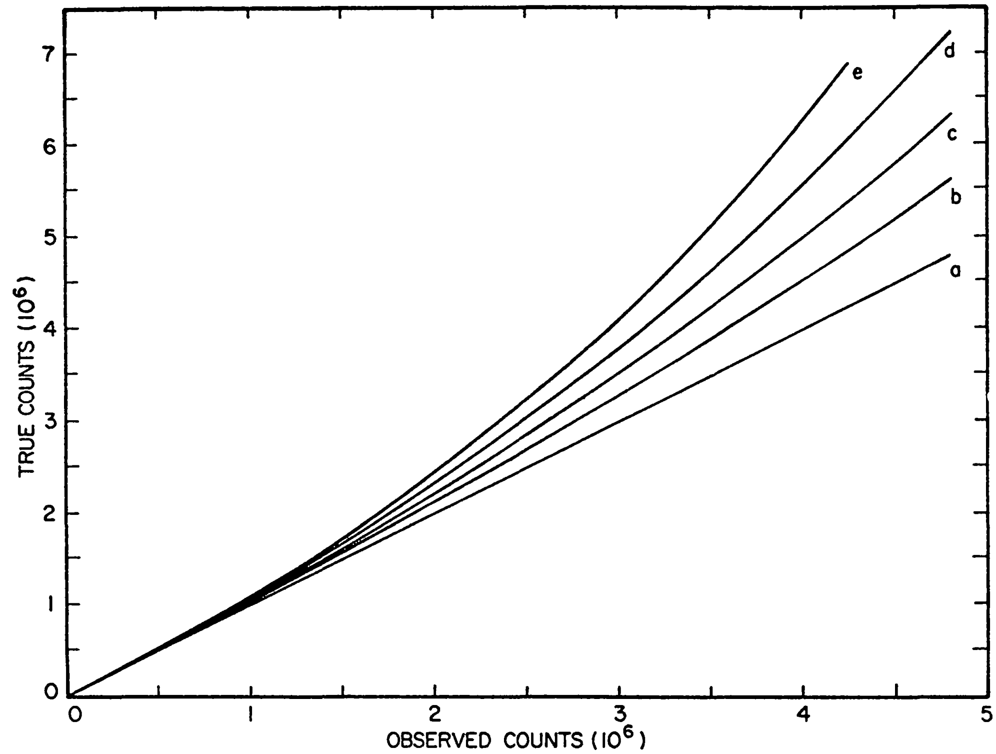

Figure 1. True count vs. observed count for various deadtimes: (a) 0, (b) 30 x 10^{-9}sec, (c) 50 x 10^{-9}sec, (d) 70 x 10^{-9}sec, (e) 90 x 10^{-9}sec.

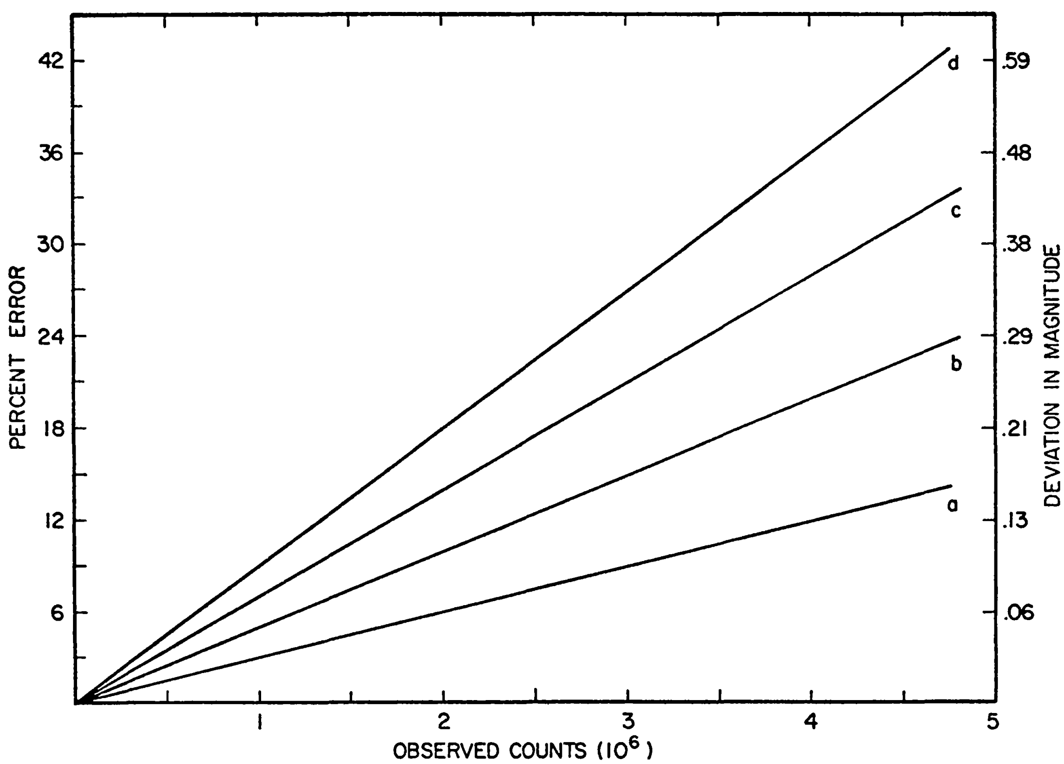

Figure 2. The scale on the left gives the percent by which the observed count falls below the true count for various deadtimes: (a) 30 x 10^{-9}sec, (b) 50 x 10^{-9}sec, (c) 70 x 10^{-9}sec, (d) 90 x 10^{-9}sec. The scale on the right gives the deviation in magnitude which must be subtracted from the magnitude derived without the deadtime correction.