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"COMETARY PHOTOMETRY: INFINITE APERTURE MAGNITUDES"

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1. INTRODUCTION

It has been known for some time, that CCD observations of comets, produce a magnitude that is several times fainter than a corresponding visual observations. The reason for this difference is not known. The effect has been studied by Mikuz and Dintinjana (2001), who found that the best cometary photometry was achieved when short focal distance lenses were used in combination with a CCD and a V filter. This demonstrates that one of the major culprits of faulty cometary magnitudes is excess focal length. The difference they found between V and m1 magnitudes was negligible for two comets, C/1995 O1 Hale-Bopp, and 103P/Hartley 2, using this methodology.

Green (1996) wrote that *"The key problem is in mixing the CCD photometry obtained when comets are fainter than mag 13 or 14 with the more uniform visual photometry obtained when comets are brighter. Near the "cross point", which is around mag 14 (the point at which visual observers generally stop because of difficulty in seeing fainter objects easily, and also the point at which CCD photometrist seem to begin having problems because the coma is getting too large), it seems that total CCD magnitudes (particularly unfiltered ones) are generally 1-3 magnitudes fainter than the total visual magnitudes made by experienced observers…..there may be a problem with the manner in which CCD magnitudes are derived (via "canned" software packages that may not subtract the background properly….) "*

The problem of discrepant CCD and visual magnitudes has survived up to the present time and in this work a possible solution is proposed.

2. INSUFFICIENT CCD APERTURE ERROR

It can be deduced from the literature that it is common to use a photometric aperture too small to measure CCD images of comets. The problem can be understood looking at Figure 1 that shows two images of comet 62P/Tsuchinshan 1, taken with the 1 meter Schmidt telescope of the National Observatory of Venezuela. This 3 minute exposure with no filter, shows the comet rendered with a normal stretching of the image in the left frame. A measuring circle of 20 pixels in radius has been drawn, and <u>it seems to be sufficient to extract a magnitude for the comet.</u>

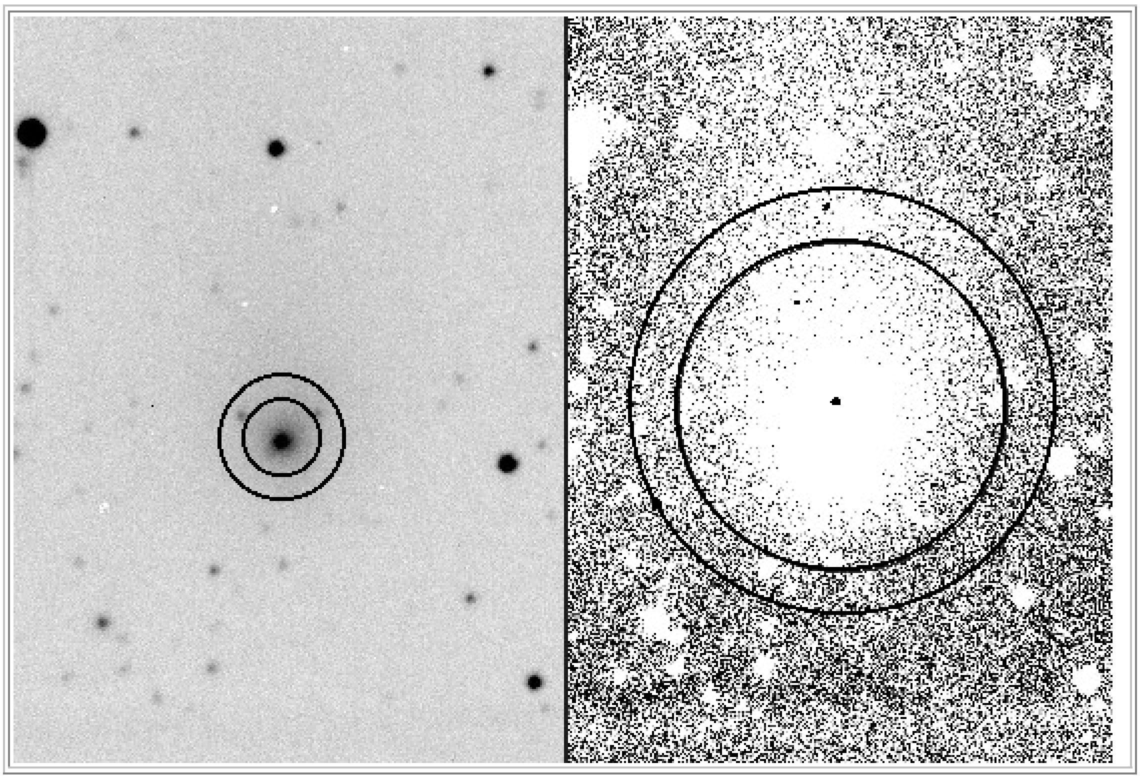

Figure 1. CCD images of comet 62P/Tsuchinshan 1 taken with the 1 meter Schmidt telescope of the National Observatory of Venezuela. The left image shows a normal stretching of the image with an inner circle of aperture radius 20 pixels believed to be sufficient to extract a magnitude. The outer circle measures the sky background. However a forced stretching on the right shows that the comet extends much farther away than previously believed. In fact the comet fills the 80 pixels aperture radius (notice that some flux is still left outside in the upper region). The 20 pixels aperture measured a value 2 magnitudes fainter than the 130 pixels aperture as can be deduced from Figure 2. This is called the Insufficient-CCD-Aperture Error.

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The lack of flux produced by this error shows up in the secular light curves of all comets studied to date (Ferrín, 2005) by falling below the

envelope of the light curves. The envelope has been shown to be the best representation of the secular light curves. Thus there is a significant dispersion of the observational points in the vertical direction (the reduced magnitude axis). If it were possible to reduce this dispersion, the envelope would be defined much more precisely.

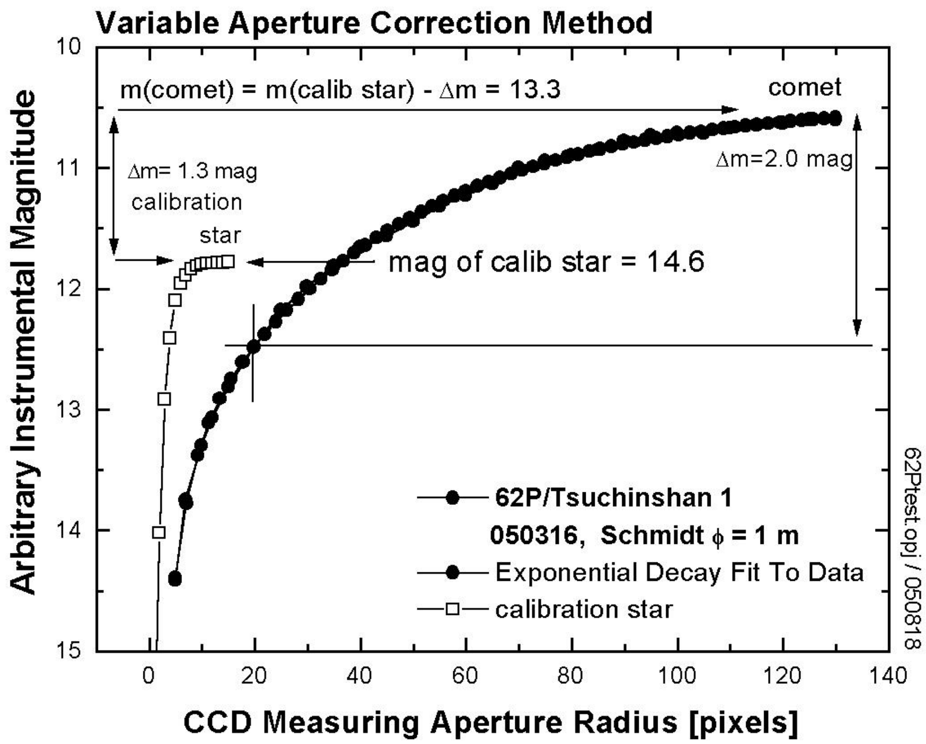

Figure 2. Variable Aperture Correction Method. To avoid the Insufficient Aperture Error described in the previous Figure 1, we propose the use of a "Variable Aperture Correction Method": The magnitude measured with increasing apertures are plotted in a magnitude vs radius plot like the one shown above. The magnitude extrapolated to infinity is the correct magnitude. The Figure shows that an aperture of 20 pixels in radius gives a value 2 magnitudes fainter than a 130 pixels radius. An this result is for a comet of magnitude 13. The situation for a brighter comet must be worst. Notice how the calibration star converges rapidly to a constant magnitude. The method uses the equation shown inside the plot to extract an infinite aperture magnitude.

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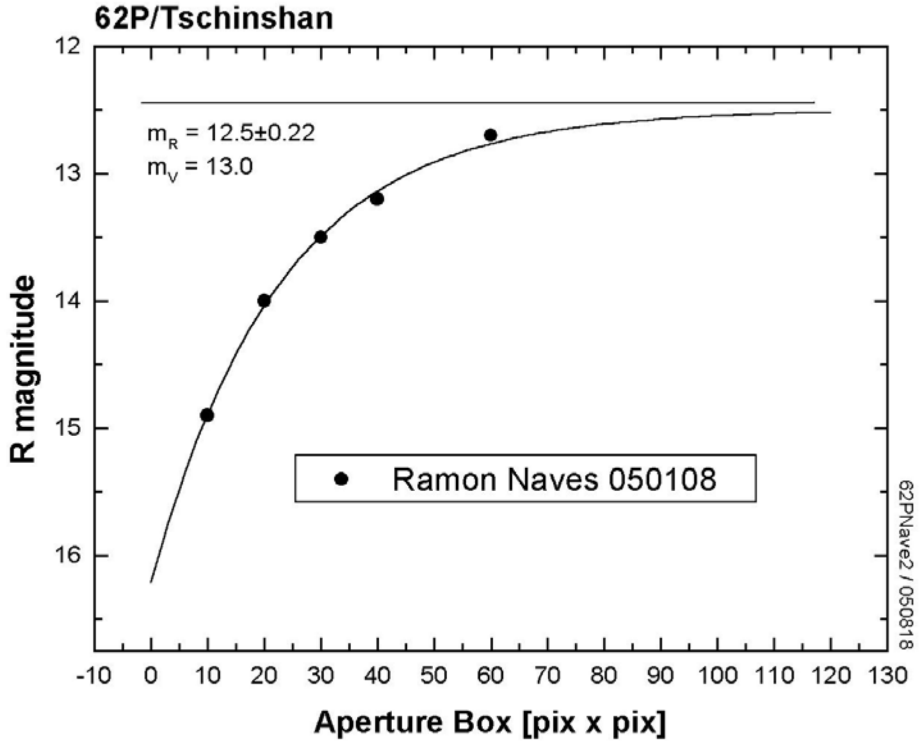

Figure 3. The insufficient-aperture error shows up also in amateur observations. Here we plot measurements by Ramon Naves of the same comet 62P. He used square-box apertures to extract a magnitude. It can be ascertained that the same lack of flux occurs in the small apertures. Notice that a 10x10 aperture measures a magnitude of 14.9, about 2.4 magnitudes fainter than the magnitude extrapolated to infinity (12.5) . His magnitudes are taken in the red and thus they must be converted to visual using V-R= 0.50 mag.

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As can be deduced from Figure 3, the insufficient-aperture error affects in the same way CCD observations taken by amateurs. In particular we show observations taken by Ramon Naves (2005). In the same issue of the ICQ in which this paper was published, Milani (2005) published the results of photometry using the Af(rho) method by the Italian CARA group. It must be mentioned that their observations as well as those of the Spanish observers, are of excellent quality. In page 243 he gives a sample table with magnitudes and Af(rho) values for comet C/2001 Q4. I have plotted his magnitudes in Figure 4, and we find the same result: all are affected by the same insufficient-CCD-aperture error.

There are additional limitations with the Af(rho) method, in that it assumes a "steady state" comet, a comet that is "stationary". However we do know that comets are some times erratic and varying in magnitude. In a sub-note by the Editor of this work (p. 241), he points out that "…there are many assumptions used in this quantity….a static picture…for the size, scattering particles and expansion velocity…"

The Infinite Aperture Method (IAM) does not make any assumptions.

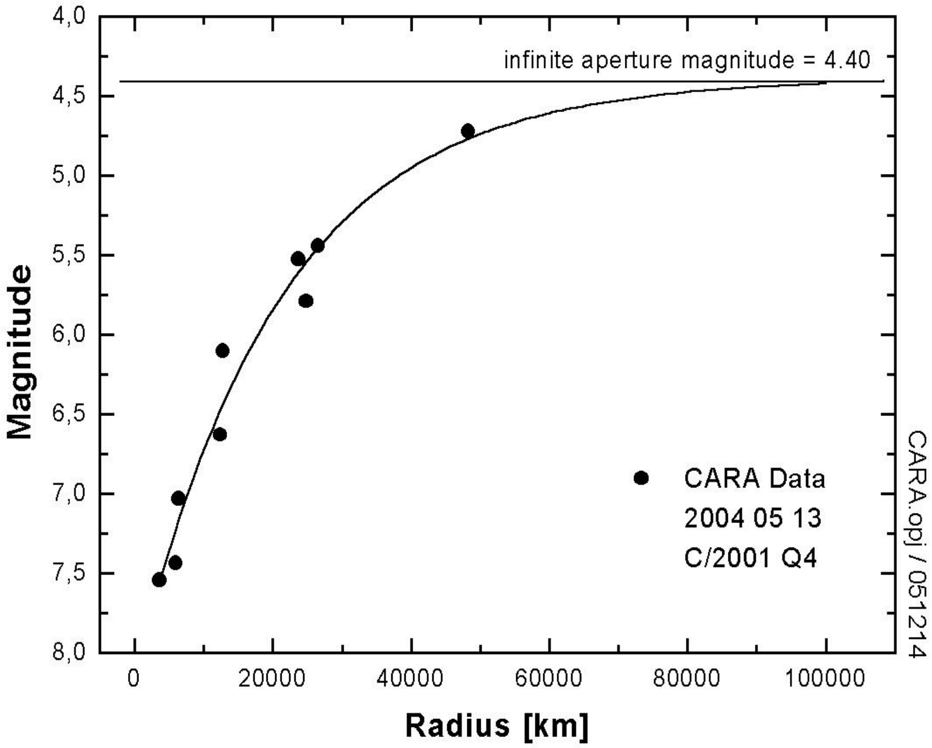

Figure 4. Insufficient-CCD-Aperture for the CARA data. We see the need to extrapolate the data to infinity to extract an infinite aperture magnitude (IAM). The data has been published by Milani (2005).

3. INFINITE APERTURE METHOD (IAM).

To avoid the Insufficient CCD Aperture Error, we propose the adoption of an "Infinite Aperture Method (IAM)" consisting of measuring the magnitude with increasing apertures, and plotting these values as a function of measuring aperture, to extract a value extrapolated to infinity, that is an "infinite aperture magnitude (IAM)". Figure 2 shows the instrumental magnitude as a function of measuring aperture for comet 62P/Tsuchinshan 1. It is concluded that the 20 pixel aperture gives a value 2 magnitudes fainter than the 130 pixel aperture. Since the scale of the telescope was 1" of arc per pixel, what this means is that an aperture of radius larger than 2 minutes of arc (120") was needed to extract a complete magnitude.

To implement the method follow these steps:

1) **Take a calibration star (one with a known magnitude), and assign to it an arbitrary magnitude of 15. The value assigned is not important because we are going to work with "differential magnitudes".**
2) **Measure the calibration star with very small apertures of 1,2,3…10**

Pixels, using a second external circle to subtract the sky background. Plot these values as in Figure 5.

3) Measure the comet now using larger apertures, 2,4,6,…..100, 102…. also using a second aperture to subtract the sky background. Plot these values too as in Figure 5.

4) Measure from the plot the magnitude difference (extrapolated to infinity) between the star and the comet , Δm.

5) Apply this difference to the comet and determine the infinite aperture measurement using the equation:

$$m(comet) = m(calibration\ star) - \Delta m$$

6) Notice that to measure with large apertures, it is first necessary to erase all faint stars around the comet, so that they do not contribute to the measuring aperture. Thus a star erasing tool is needed to perform this task. There is no need to add noise to the erased area if the mean value of the erased pixels is identical to the surrounding area. Also, do not worry of erasing faint stars because the scale is logarithmic and a faint star does not contribute much to the final flux. Erase only bright stars that may fall inside the aperture. As a final check you can make a horizontal profile to see if the star was properly erased (it should be flat).

4. RECOMMENDATIONS TO OBSERVERS.

The moral of this tale is to use the smallest focal distance possible, sufficient to show the comet.

There are several recommendations to observers:

1) Visual cometary observers should have several instruments: the naked eye, binoculars, a small telescope, and a large telescope, and use them according to the brightness of the object. Use always the smallest focal distance and magnification sufficient to show the comet.

2) CCD Observers. Continue using several apertures to measure the magnitude of the comet. Apertures should be round (not square). A recommended set is 10, 20, 30, 40, 50 and 60 pixels in diameter.

3) Use the infinite aperture method (IAM) to ensure that a total magnitude is extracted.

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