

## **Obtaining multiaperture photometric measures within a normalized working environment: FoCAs software tool.**

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**Abstract.** CCD photometry of comets has been suffering of a big dispersion of the obtained measures since the use of that sort of devices was brought to general use between the amateur astronomers. This dispersion is, to a large extent, because of the lack of a standard method of work. The observers grouped around electronic mailing list “Cometas\_Obs” have tested a method that, in a few words, consists in using a fixed photometric aperture of 10x10 arcseconds. Dispersion induced by the use of different catalogs has been minimized by using “R” band of USNO A2.0 catalog only, the one that better fitted to spectral response of most commercial CCDs when taking unfiltered images. On the other hand, none of the available software was able to adapt to the requirements of 10x10 method, so a specific software tool “10x10 compliant” was developed: “FoCAs”. The program is based on another one widely used by amateur astronomers around the world: Astrometrica, known by its proved quality. We don’t want to consider this work as the ultimate one but a method’s proposal, with the intention of contributing to go a step forward towards the development of a more accurate photometry of comets.

### **1. Introduction.**

In may 2001 some observers of comets -mostly Spanish-, who were in touch trough e-mail more or less frequently, decided to gather ourselves around an internet mailing list –Cometas\_Obs-. The goal was the communications between members could be as quick and smooth as possible. From list formation, an intensive exchange of measures, images, comments, requests, and so on was started that at first served to get an idea about how the observational field showed at that moment.

One of the problems CCD observers were worried about was the dispersion of measures. In fact, there were a lot of variable factors that affected the measures we were obtaining regularly: the use of different optics, cameras, catalogs and measuring methods produced final results with a dispersion rate that gave us to understand that they were not useful at all.

After weeks of discussion where many list members were involved, we decided to establish two recommendations to the observers: the adoption of a photometric box of 10x10 arcseconds and the use, when possible, of USNO A2.0 catalog. There was obvious that with these two changes only, it was not possible to make an end of the dispersion because of the existence of other intervening factors but, at least in our opinion, we thought that we could be making one step forward and, therefore, it was convenient to test them.

### **2. FoCAs predecessors.**

When we tried to put recommendations generated in that discussion into practice, we began to find problems with commercial photometry software. Some did not support USNO A2.0 and none of them could work with an exact photometric box of 10x10 arcseconds. The ones that allowed selection of a specific aperture, always did it being based on enter pixels, while we needed a reading of a fraction of a pixel. In addition, this requirement conducted us to another one: the most accurate centroid calculation we could achieve. Another problem was related with calculation of the sky background. Some software allowed selection by the observer of a piece of the image to perform the corresponding subtraction, but some other used a ring around the comet’s nucleus. The consequence was, in most cases, the contamination of the reading because of tail or coma and the final result was a measure with values fainter than actual.

The only reliable way out from this situation was programming an application that could get the requirements we had established when considering how to obtain the measures. We have already mentioned that one of the critical points to obtain a reliable 10x10 photometric measure is a correct centroid determination. We were starting from a reference point: a series of analysis performed with the collaboration of a lot of observers had concluded that the commercial software with the least dispersion

was AstroArt, so we decided to make good use of the advantages it gave to apply them when developing our own program that was named Fase3.

AstroArt is not pointed towards astrometric and photometric measures. Despite of the ability already mentioned for centroid calculation, the procedure to perform the measures is extremely bothersome: it is required to open a window with the image to measure, to open another one with a chart generated from the catalog information and then select reference stars one by one in both image and chart. And you must repeat every step for every image! However, the program allows, with a few mouse clicks, having a report of the present objects in an image with their corresponding calculated centroids and some other interesting data. One of the first tasks completed was the development of a half-automated procedure to find correlation between image and catalog. Fase3 made up two synthetic images from AstroArt and catalog data. The user must select a pair of stars in both synthetic images and then the program matched stars in the image with their corresponding pairs on catalog.

One time this step was accomplished and knowing observers optical systems data, we were able to perform the photometric measures with accuracy of fractions of a pixel, measuring, in this way, with the 10x10 arcseconds photometric aperture we had proposed ourselves. In addition, Fase3 also made astrometric calculations, and then it was able to produce MPC reports as well as those with destination to Cometas\_Obs database.

### **3. Astrometrica**

We were working with Fase3 at full performance for almost one year. However, though measures quality was being constantly checked (fewer dispersion in photometry and excellent residuals in astrometry), the procedure to obtain them still implied a hard work for observers. For example, we could quote the need to extract AstroArt data image by image and the need to have a folder and archive names structure very rigid, although this second feature partly helped to make the process automation easier.

About the first half of 2003, some observers started to use Astrometrica to make astrometric measures. Then, they started to talk about its amazing simplicity of use. With a few mouse clicks the measures were generated, showing in addition an excellent quality, highly more accurate than those generated by AstroArt. However, one more time the procedure to obtain photometric measures did not fulfill with the requirements that were observers main objective. The selection of an aperture radius of enter pixels went away from our intention of working with fractions of a pixel, and we had again to confront with the problem that meant the contamination of photometric measures results due to the use of a ring around the object to measure as the way to subtract the image background as previously explained above in point two.

Fortunately, we soon discovered that Astrometrica was hiding a little treasure. "Astrometrica.log" archive, generated every time a measure was performed, contained all the information needed for our purposes: reference stars centroids and, although the catalog magnitudes were not directly showed, the measured magnitude and the error were, and then, the obtention of the first was immediate. With all tools within reach, developing a program that could make good use of well known quality of Astrometrica to produce photometric measures according to our criterion was relatively easy. The new program was named Focas (FOtometria Con AStrometrica, or Photometry with Astrometrica in English).

### **4. Astrometry with FoCAs.**

This section was the easier to program. Given the well known quality of the measures generated by Astrometrica, they are only imported to the corresponding reports. Later, we will see that UCAC and USNO B1.0 are not taken as acceptable for photometric calculations, but if they are used to perform some measures, the astrometric results obtained will be transferred.

### **5. Photometry with FoCAs.**

#### **5.1 Resolution.**

We have already said that one of FoCAs goals is to perform photometry with a 10x10 arcseconds exact aperture. Thus, the first step to perform measures of the images is the reading of observers optical system data from configuration archive of Astrometrica and then do the calculation of resolution in arcseconds/pixel.

## 5.2 Image background.

The following step is the image background calculation. After performing tests with several procedures, that with the better results is quite easy: the average of all pixels is calculated, then those with ADU values greater than 10% of the average are discarded and averaging calculations with the remaining pixels are repeated.

## 5.3 Photometry calculation.

Photometry calculation. The level of ADU contained in a 10x10 arcseconds area is calculated for every star in the catalog. For it, the optical set resolution is considered and the level of ADU in each pixel, starting in the centroid, calculated by Astrometrica is added. For pixels placed on the 10" limit, the program computes the corresponding fraction. Later, for each star the reference magnitude (that corresponding to one ADU) is determined, through the expression (1) below:

$$MZ = \text{mag}(\text{catalog}) + 2.5 \log(\text{ADU}) \quad (1)$$

Next step consists in determining average MZ and calculating the magnitude for each star with the expression (2):

$$\text{mag}(\text{calculated}) = MZ - 2.5 \log(\text{ADU}) \quad (2)$$

Last step consists in comparing the magnitude calculated in this way with that obtained from the catalog, rejecting stars with an error larger than established by the user in Astrometrica configuration file and calculating again MZ with the remaining stars only. Last, the magnitude of the object to measure is calculated applying expression (2) again.

## 5.4 Other considerations.

FoCAs also takes into account the limit of linearity of CCD cameras. If the user knows this value or he has calculated it and he has correctly introduced into the corresponding box in Astrometrica, the program will discard right away the stars with a value in ADU greater than specified. It will also report if it is occurring the same with the object to measure, giving to the user the possibility to discard that measure.

## 6. Other apertures, photometry report.

With intention of providing with the most information to final users of our data, FoCAs also calculates photometry with apertures of 20x20, 30x30, 40x40 and 60x60 arcseconds. In addition, other data of interest as SNR (signal-to-noise ratio), sky background brightness in magnitude/square arcsecond and catalog and color band used are included into report.

OBJECT	DATE	HOUR	10X10	20X20	30X30	40X40	60X60	SNR	SB	BAND/CATALOG	COD
40P	21/03/2004	01:44:51	15.8	15.1	14.8	14.8		8.7	18.5	R USNO-A2.0	939
117P	21/03/2004	00:05:12	17.3	17.1				5.9	18.7	R USNO-A2.0	939
118P	20/03/2004	22:15:02	15.4	14.7	14.5	14.4	14.3	11.6	18.6	R USNO-A2.0	939
123P	20/03/2004	23:21:07	14.8	14.0	13.7	13.5	13.3	13.3	18.5	R USNO-A2.0	939
C/2003 H1	20/03/2004	23:08:35	14.5	13.6	13.3	13.1	12.8	11.5	18.1	R USNO-A2.0	939
C/2003 K4	21/03/2004	04:14:30	13.2	12.4	12.0	11.6	11.4	34.1	18.4	R USNO-A2.0	939
P/2002 T5	20/03/2004	22:35:00	17.0	16.4	16.4			5.5	19.0	R USNO-A2.0	939

## 7. 10x10 measures correction depending on the distance.

The use of a fixed 10" aperture implies that we are going to measure different pieces of different size of the comets as distance between them and the observer varies. Using of photometric boxes of variable size, depending on the distance of the comet to Earth, will add an extra complication, demanding the observers to calculate the apparent size of the coma or a fixed piece of its diameter and the use of different apertures for each comet and each day of observation. A fixed photometric box implies, as mentioned, the observation of variable pieces of the coma. Therefore, it is necessary to correct this effect to perform a right data analysis.

When a comet approaches to or recedes from the observer, its apparent diameter changes in linear relation with the distance but its apparent surface does proportionally to the square of that distance. And so, we must multiply the observed brightness by a factor proportional to the square of the distance variation to correct this effect. The correction, expressed in magnitudes, will be done by expression (3):

$$\text{mag}(\text{corrected}) = \text{mag}(\text{calculated}) - 5 \log(x/d) \quad (3)$$

Where  $x$  is a distance of reference we will choose depending on the actual piece of comet we would want to consider. In our work, we have decided to measure a diameter of the coma of 25000 km. An arc of 10" covers the selected diameter of 25000 km. from a distance of 3.5 A.U. Therefore, final correction for a fixed diameter of the coma of 25000 km. will be expressed as (4):

$$\text{mag}(\text{corrected}) = \text{mag}(\text{calculated}) - 5 \log(3.5/d) \quad (4)$$

However, we must notice here that the measures obtained by FoCAs are not affected by this correction, so we leave in hands of the users performing or not the corrections they estimate appropriate.

## **8. The image background issue.**

The use of the whole image to calculate the background requires to the users a very careful processing, especially all that related with flat fielding. If this is deficient, the accuracy of the measures will probably be seriously affected. It is also necessary to get the best SNR you can reach. Measures with larger apertures contain an important part of image background and if SNR decreases, errors could also appear. FoCAs has tools to remove probably erroneous measures. A decrease in brightness in larger apertures (that would point to a background overestimation) or an excessive increase (possibly produced by the presence of some star in the affected area) provoke the measures to be discarded and they are not included in the reports.

## **9. The catalogs.**

Although at first FoCAs could be able to work with all catalogs and color bands supported by Astrometrica, we have decided to limit, for the case of photometry of comets, the use to only one: USNO A2.0 and one color band: "R" band.

UCAC catalog was not developed to make use of it as a base to do photometry of quality and was quickly discarded. The possibility to make use of USNO B1.0 was widely debated on the list, some articles were consulted and we came to the conclusion that this catalog did not warranted enough accuracy, so that it also was discarded.

The use of other "photometric" catalogs as Tycho is not completely discarded. However, its application is difficult because it is very unlikely to find the needed number of stars in the very small field of view offered by CCD chips and, in addition, these stars will be, almost for sure, much brighter than the comets we usually observe.

As for the sole use of "R" band, is due to that spectral response of unfiltered images taken with CCD cameras tends to have a peak towards this band and the results are much more coherent that with the use of other bands.

## **10. Justification of the photometry without filters.**

At this time of writing, the photometry without filters may look as not justifiable. However, after removing some of the contributing factors to the dispersion of the measures, we have noticed that our results have substantially improved. We have to take into account that most observers use telescopes with diameters between 20 and 30 cm. and that the sky quality in observing locations is, in most cases, far from ideal. In this conditions, the use of filters would cause a significant part of comets now within our reach to be out of our possibilities of observation.

## **11. Photometry of supernovae.**

Although the observation of this sort of objects was not foreseen in the beginning, we have found that using an aperture of 10x10 arcseconds solve in many occasions the issue with contamination of measures because of the presence of the galactic nucleus. In this meaning, we find equally valid the considerations about photometry without filters mentioned above with comets. The use of filters would put the most supernovae out of reach.

## **12. Other FoCAs features.**

As a complement to photometry calculation, FoCAs brings other functions that may be useful for the observers: multiaperture photometry reports for comets, MPC format for asteroids and comets, VSNET format for supernovae and it also counts with an e-mail client, that makes easy to send obtained data up to four different addresses simultaneously.

## **13. Future improvements.**

FoCAs continues growing partly thank to contributions and suggestions by the users. Multiaperture photometry calculation, supernovae support and possibility to send reports through e-mail are signs of it.

In addition, there are two features pending of development that were already present on its predecessor Fase3. The first one would bring the functional character needed to perform light curve analysis of asteroids or short period variables and the second, related with former one, would allow analysis of changes in brightness for all the reference stars present in the images, with the goal to make easier to detect possible new variable stars.

## **14. Summary.**

FoCAs is not an attempt to be the final word in relation to photometry of comets. We are conscious of its limitations but, even taking them in mind, we believe that it presents an advance in relation to solving the main problem affecting to this sort of observations: dispersion of results. In that sense, it would not be taken as a solution but as a proposal of method that we think may be useful.

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445 Ontinyent, Miquel Camarasa  
458 Guadarrama, Diego Rodríguez  
844 Los Molinos OALM, Fernanda Artigue  
859 Wykrota-Ceamig, Cristovao Jacques  
939 Rodeno, Julio Castellano  
945 Monte Deva, José Ramón Vidal Blanco  
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V12 Diego Rodríguez  
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AMO Alexandre Amorim  
QUI Frederico Paiva Quintao  
BUS Víctor Angel Buso

#### **Appendix A. Cometas\_Obs database.**

Eventually, Cometas\_Obs members have been collecting a big amount of data. More than 19000 observations are available for anyone who would need them to perform analyses or studies. An important amount of other material have also been collected: images, articles of our own, translations, observing aids, software, and so on that may be consulted and used by anyone that would need it or, merely would be feeling like attracted by the world of comets. Everything is put together on our web page:

<http://www.astrosurf.com/cometas-obs>

Of course, the more dynamic way to contact us is the e-mail list where anyone interested in this topic is welcome, from people who, for the first time, come close to this fascinating field of the astronomy to the more advanced observers. The contact site is placed at the following URL:

[http://es.groups.yahoo.com/group/Cometas\\_Obs](http://es.groups.yahoo.com/group/Cometas_Obs)

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