Aperture photometry of cometary comae using CCD cameras

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Contents

1 Introduction

Purpose of this observing program is to set-up and guide a photometric survey of comets that are within the range of amatorial instruments equipped with CCD cameras.

Aperture photometry applied to the cometary comae studies is considered an interesting technique, providing useful scientific data even on that objects, the majority indeed, with poor or less details.

This technique allows the observers to achieve a good qualitative standard with a relatively simple method. The observers must be awared that aperture photometry requires some amount of time for data reduction. Consequently the numbers and type of observing runs has be suitable to the data analysis capability.

In this program, observers are asked to perform by theirself the first steps of data reduction. This method allows to immediatly achieve useful datas, even for the professional astronomical community.

This program was born thanks to the observing work and experimentation carried out from 1996 to 2001, within the Comet Section of Italian Amateru Astronomer Association[1] and in particular in the Group of Cometary Observers[2], a group of active amateur astronomers that worked with a constant exchange of data and experiences by e-mails.

2 The photometric quantities

One of the problems in the cometary photometry, intended here in the classical way of determining the total coma magnitude (i.e. integrated magnitude) is that it is strongly affected both by instrumental and sky conditions, as well as subjective ones. Due to these and other reasons this tecnique have several limitations.

Considering only the field covered by visual observations, total magnitude estimates have still their meanings in being comparable to hystorical data obtained in the past centuries. On the other hand, the total magnitude so intended do not allows to obtain the most from the actual digital techniques.

In professional astronomy cometary photometry is used to determine the production rate of gas and dust as well as the size and properties of the nucleus. This is performed using narrow-band filters, centered on a particular spectral window for isolating particular gas emissions or reflected light by the comet dust (i.e continuum). These filters do not achieve high efficiency when coupled with amatorial equipment used in standard amatorial environmental sky conditions. Trials on bright comets did not give certain

[1] formerly U.A.I.= Unione Astrofili Italiani

[2] formerly the G.O.C. = Gruppo Osservatori Comete

results. Wide band filters (i.e. BVRI bands) are more affordable and in some cases unfiltered CCD can also be used, providing a previously appropriate calibration.

For studying of dust is now commonly used the $Af_{[\rho]}$ quantity (hereafter called Afrho), introduced by A'Hearn [1] [2] in 1984. This quantity can be interpreted as the size of an hypotetical dust disk that reflects the same amount of light as reflected by the dust coma. Dimensions are generally given in centimeter or meter, depending on the more convenient unit. So we moved from a brightness measure (magnitude) to a linear one, strictly related to the chemical and physical properties of the dust component.

Afrho is sometimes used to determine the dust rate production by a comet, assuming as representative of the total mass of the dust, predefined dimension and albedo. Obviously this approach needs some "ad hoc" assumptions, using values obtained from other comets observations.

A furthermore limitation is that the obtained value is reliable only if the dust coma match the constant speed radial expansion stationary model.

Altough of this limitation, Afrho is an important value since whatever model is being used to study cometary dusts, has to be compatible with the Afrho value obtained.

Moreover, this quantity lends itself to other considerations, in example if the powders match the constant speed radial expansion model and how far from the nucleus the interaction with the radiation pressure assumes an important rule.

Further considerations could achieved by comparing Afrho values respect to other quantities obtined with other observing techniques.

Advantages on using this technique are:

- determination of Afrho is not affected by the instrumental characteristics and datas obtained with different set-up and under different geometrical conditions can be compared, even if the optimal condition is achieved using:
  - ⋆ narrow band filters, centered on region dominated by reflected light from the dust
  - ⋆ spectral analysis
  - ⋆ using large band filters
  - ⋆ even with the not filtered observation, in integral light, it is possible to obtain interesting results. Taking as refenrence dusty comets as the Hale-Bopp, observed without filters, Afrho is then overestimated by a 10%. This situation can be improved using large band filters

- datas obtained better reflect the comet activity, and the use of standard filters highlight variations in the gas production (i.e. the V Johnson filter is centered on the C_2 emission)
- datas obtained are directly comparable with professional ones
- creation of a database becomes more easy to set-up and more readble respect to an equivalent made up by magnitude values

3 Observing method

The Afrho determination is based upon the aperture photometry using differents measuring windows sizes, all centered in the comets nucleus. Since the result is not related to the measuring window size, the method is very versatile and allows the observer to use etherogeneus instruments, with different focal lengths or apertures, without any particular drawbacks.

Aperture photometry is even applicable on cometary studies, keeping in mind some basic rules.

The GOC and Sezione Comete's observers are currently using the software Astroart[3] for their data analysis. This software running on Windows™ platforms, only allows the use of square windows and consequently the observing survey program has been adapted to. We expected and encourage that all the people involved in the survey are going to use this method.

In the case of some observer is going to use the circular windows method it is better to contact the program coordinator (the author).

3.1 Suggestions, tips & tricks

- Measuring windows should be made up by an odd pixels number. This allows the observer to put the comet fake nucleus in the windows center.
- The minimun measuring aperture has to be compatible respect to the images effective resolution. Little windows are influenced by out-of-focus problems, guide errors, atmospheric turbulence, and generate wrong Afrho quantities.
- Use at least three different aperture size in order to verify the constantness of the Afrho value.
- Determination of the sky background value is a very sensitive and important task. Usually, considering the maximum value of the istogram generated by a sky area with little stars, should approximate the sky

[3] MSB Software - http://www.msb-astroart.com

background very close. Others methods could be valid as well. A not correct evaluation of the sky background implies errors.

- Exposures time has to be set in order to NEVER, never reach the CCD saturation level both for the comet and the comparing stars. If the comet is a dim one it could be easy to sum more images, centered in the fake nucleus in order to improve the signal to noise ratio and precision of the measures. In presence of brighter comets it could be useful to averages more images.

- Bright stars eventually "placed" over the coma should be removed with a make up procedure, adjusting the coma luminosity respect to the area surrounding the star. Presence of dimmer stars respect to the comet coma is not a very big deal for the measure.

- Suggested filters for general studies are the R and I from the Cousins standards, and in second instance the V filter from the Johnson standard. It is not excluded the use of narrow band filter whenever possible. Observations made without filters has to be referenced to the band nearest the CCD sensitivity peak (generally V or R). Determination of the cited band and relative correction needs an appropriate calibration using a standard field (i.e. the M67 open cluster).

- Considering the complications involved using filters, we suggest to limits their numbers; the most useful are the couples V, I and V, R. If planning to use just one filter give the priority to I or R; they cover band regions with less gaseous emissions and the real Afrho value is then better approximated.

- It would be better the use of comparing stars originated from the Tycho e Hypparcus catalogues, wich have a good sky coverage. Others catalogues with good precision (i.e. Bright Star Catalog) could be used. In general the use of catalogues made up with photoelectric datas, wich give the V magnitude and the $B-V$ color index (Johnson), are preferrable. The choice of comparing stars should be fall in those whose color index is $0 < B-V < 1$, avoiding the reddish ones ($B-V > 1$).

- Stars in the same comets field should be used. If it is not possible, take a snapshot of a nearby star possibly at not more than 1 degree far away (to minimize the sky differences).

- Exposure time for the comparing stars should fall between 5 and 10 seconds. In case of short time exposures the atmospheric scintillation becames an important factor, so it is better to average 5 to 10 snapshots. Verify the CCD shutter timing on both operations, expecially if it is a mechanical one that could introduce systematic errors.

- The images has to be pre-treated before the measuring process. The corresponding dark frame[4] has to be subtracted and consequently divided by the il flat field [5], assuming that observers has used to these procedures. Both dark frames and flat fields are made up by averaging more snapshots.

4 Data Analysis Program

To simplify the data analysis a simple program has been compiled. It allows to obtain the Afrho quantities from the ADU counts measured using the aperture fphotometry technique.
Hereafter the requested parameters:

- Earth-Comet distance in A.U. at the observing date/time (note: use valid orbital elements for the considered epoch)
- Sun-Comet distance in A.U. at the observing date/time (note: as mentioned above)
- x and y pixel dimensions of the used CCD, expressed in arcseconds
- V magnitude of the comparing star
- B-V color index of the comparing star

after calculating the R and I magnitudes for the reference star, the program requires the following parameters:

- photometric band selection (B,V,R,I)
- ADU counts of the comparing star (where the sky background has been subtracted)
- Exposure time for the reference star
- Exposure time for the comet [6]
- Window size in pixels (base)
- ADU counts for the comet (where the sky background has been subtracted)

The program calculates and prints out these values

[4] Image generated by the CCDs dark current, obtained with a closed shutter at the same exposure time and temperatures of the reference image

[5] Image of a uniformerly illuminated field wher tits dark frame has been already subtracted

[6] If the exposure times are equal use the value = 1 for both parameters

- comet magnitude respect to the considered measuring window
- radius, in km, of the considered coma region (equivalent radius of the square measuring window keeping in account the coma luminosity gradient)
- Afrho quantity, espressed in cm
- indicative error on the Afrho quantity, for an hypotetical error of 0.05 in the magnitude calculus

5 Notes

5.1 Notes on the AFRHO quantity

The Afrho quantity is calculated by the ratio betwwen the luminous flux received from the comet, and the solar flux, using the following equation:

$$Af_{[\rho]} = \left(\frac{2DR}{\rho}\right)^2 \left(\frac{Fc}{Fs}\right) \rho$$

where:

- A is the albedo
- f is the fullfilling factor, that is how much the powder grains fill the field of view
- ρ is the coma radium considered in the measurement, usually expressed in cm
- D is the geocentric distance Earth-Comet, expressed in cm
- R is the eliocentric distance, expressed in Astronomical Unit
- Fc is the observed comet light flux (or flow)
- Fs is the solar flux at 1 AU

The fullfilling factor (f) is usually less less than 1 $f \ll 1$ due to the fact that the dust grains don't fullfill completely the field of view. Only in the case of the Hale-Bopp comet, the inner region resulted completely matt due to the high dust density ($f = 1$). Some authors uses the geometrical albedo $A(\Phi)p$ defined as the ratio between the incident radiation reflected perpendicularly to the surface, and the incident radiation intensity. In this case the value of the Afrho quantity becames 4 times lower respect the albedo showed in the original A'Hearn's equation, wich consider the overall radiation reflected by a body (albedo defined by George P. Bond in 1861).

5.2 Notes on the comparing star magnitudes

In order to obtain and use an homogeneus source assuring a good sky coverage, we chosed as main source the Tycho e Hypparcus catalogues. Starting from the V magnitude and the B-V color index, the R and I magnitudes have been extrapolated using sixth degrees polynomes extracted from the Bright Northern Standard list, one of the better sources of multicolor magnitudes of bright star in the northern emisphere, compiled by Brian Skiff. The precision of the method assure a pretty good precision. Stars data from the Tycho e Hypparcus catalogues have been extracted from Guide [7] software, versions 6.0 and 8.0.

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7 Appendix A

7.1 Solar Parameters, conversion factors, costants

- Solar magnitudes and colors:

  V = -26.71
  U-B = -0.20
  B-V = 0.67
  V-R = 0.36
  V-I = 0.69

- Km/arcseconds at 1 AU = 727

- Equivalence constant between circular and square aperture

  $r = 0.5611 \cdot L$ with gradient $1/r$

  $r = 0.5642 \cdot L$ area equivalence

  Where r is the radius and L is side length of the considered window.

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