A-PHOT version 2.1 - Documentation

E. Merlin

November 27, 2018

1 Introduction

A-PHOT computes aperture photometry (in many different flavors) on astronomical images.

Unlikely its more famous relatives like SExtractor, it is designed to perform photometric measurements requiring a detection catalog as *input*. This has the advantage of giving the full control on the process of flux measurements, detaching it from other duties and making it more transparent, and allowing for the repetition of several measurements on the very same detection. It is also possible to compute and subtract a local background (see Sect. 6), and some morphological parameters can be computed internally provided a segmentation map is given (namely, semi-axis lengths, ellipticity, position angle, and Kron radius; see Sect. 7).

2 Installation

A-PHOT consists of a Python wrapper calling C core-codes. It just requires the `CFITSIO` library. To install it, open the tarball and cd to the `aphot` directory. Edit the script INSTALL.PY indicating the path to the `CFITSIO` installation folder, and then simply give

```
$ ./install.py
```

If no errors are thrown, include the `bin/` directory that has been created in your `PATH` variable, and that's it.

3 Input

As input, A-PHOT needs:

- a scientific image in FITS format, on which the photometric measurement is being made;
- the corresponding RMS map, in FITS format, to compute the uncertainties;

- optionally, a segmentation map and/or a flag map (where 0 flags "good" pixels and any number >1 flags pixels that will not be considered in the computations), again in FITS format;

- an input catalog listing IDs, x and y centroid positions, and morphological parameters of the detected objects, namely: the major semi-axis R_1 of the ellipse that will be used for the elliptical apertures measurement, its ellipticity defined as $e = 1 - b/a$ where a and b are the major and minor semi-axis respectively, and the position angle θ. The x, y positions can be given in pixel space or in WCS: if they are given in pixel space, then R_1 must be in pixels as well, while θ (in degrees) is defined as the counter-clockwise angle between the pixles grid X axis and the major semi-axis of the objects. Instead, to use WCS positions (RA and DEC) the keyword `WCScat` in the configuration file must be set to `True` and R_1 must be given in arcseconds (A-PHOT then uses the `astropy.wcs` module to convert coordinates and dimensions from WCS to pixel space, writing new catalogs in pixel space, to be fed to the core software); in this case, θ is defined as the counter-clockwise angle between the equatorial plane and the major semi-axis of the objects.

  To compute the morphological parameters internally, a *computing radius* must be given for each object, defining the circular area on which the pixels operations will be performed. This radius must be given in the input catalogue, in place of the major semi-axis R_1, *preceded by a negative sign.* The ellipticity can have any value (it will be ignored), while θ can be forced to a previously determined value (given as input in the catalogue) or re-computed from scratch - to do so, *a value larger than 500 must be given as input.*

- a configuration file in which the locations/paths to the above mentioned data are listed, along with a few more, among which:

  - a list of *diamaters* (in pixels or arcseconds, depending on the units of the xy positions), for circular aperture flux computations (they must be separated by a coma);
  - a list of *multiplicative factors* that will be used to shrink and/or enlarge the major semi-axis given in the input catalogue, to output multiple elliptical aperture fluxes (they must be separated by a coma); if this list is just "0", then A-PHOT will automatically compute the extension of the major semi-axis which maximizes the signal-to-noise ratio, and output the flux corresponding to such aperture;
  - an integer indicating the number of subpixels (along one axis) in which a pixel partially overlapping with an aperture will be subdivided into;
  - the value of the `GAIN` of the instrument, used to compute the photon noise (it must be put equal to `-1` to exclude it from the computation);

– the name of the output catalogue.

The configuration file can be printed to a file APHOT.CONF with the command `aphot -p`. Also, see the files in the `test` subfolder as an example of the needed inputs.

A-PHOT comes with a Python module, SEX_2_APHOT.PY, that can be used to prepare the input catalogue starting from a standard SEXTRACTOR detection catalogue[1]. The script can also prepare the catalogue in case morphological parameters are computed internally. To this aim, the option `-m` must be given in the command line; the script will compute the *computing radius* for each object as $3\sqrt{2} \times r_{max}$, where r_{max} is computed considering the values `XMIN_IMAGE, YMIN_IMAGE, XMAX_IMAGE, YMAX_IMAGE`.

4 Output

The output catalogue lists:

- ID
- x and y pixel coordinates;
- the fluxes computed within the desired circular apertures (in the same uits of the image or, if the keyword `microJy` is set to `True` and a photometric zero-point (keyword `zp`) is given in the configuration file, directly in μJy);
- the fluxes computed within the desired elliptical apertures;
- the uncertainties corresponding to the circular apertures;
- the uncertainties corresponding to the elliptical apertures;
- the values of the brightest pixels within each object's segmentation;
- a quality flag, (see Table 1; the flags are similar to the ones defined in SEXTRACTOR);
- if required, the value of the measured background *per pixel*.

If required, two additional catalogues can be produced:

- one in which measured fluxes and corresponding uncertainties are converted into magnitudes, using the photometric calibration given by the `zp` keyword in the input parameter file, plus the value of the brightest pixel is

[1]Elliptical apertures are computed starting from SExtractor parameters `ELONGATION, KRON_RADIUS, THETA_IMAGE` and a constant multiplicative factor k (taken equal to 2.5 as default, but freely adjustable; see SEXTRACTOR manual, Sect 10.4).

For each object, the major semi-axes R_1 is *not* computed as $R_1 = \mathrm{MAX}(k \times \mathrm{KRON\_RADIUS} \times \mathrm{ELONGATION}, a_{min})$ as it might seem correct from the SEXTRACTOR manual, but simply as (from the unofficial user's guide *SExtractor for dummies*): $R_1 = \mathrm{MAX}(\mathrm{KRON\_RADIUS} \times \mathrm{A\_IMAGE}, a_{min})$.

Table 1: Photometric flags

Flag	Description
+0	Regular source
+1	Source is contaminated by close neighbors, or has bad pixels
+2	Source is blended with another one
+4	Source is saturated
+8	Source is close to a border

given in magnitudes per squared arcsecond (corresponding to the `MU_MAX` value in SExtractor) and the photometric flag. The pixel scale must be given as input as well;

- one listing the morphological parameters (major semi-axis, ellipticity, position angle), in case they are computed internally.

It is also possible to output a diagnostic map where all the apertures are drawn, recompiling the code uncommenting the option `WRITEAPERIM` in the file `src/aphot.c`.

5 Fluxes computation

To obtain the fluxes within a given (circular or elliptical) aperture, A-PHOT first sums the values of the pixels which fall *completely* inside the aperture. Then, it considers the pixels overlapping with the border of the aperture, it divides each of them into a grid of $n \times n$ sub-pixels (where n is the value given in the configuration file) and iterates the procedure including the sub-pixels falling inside the aperture.[2]

Uncertainties are straightforwardly computed from the RMS map, as the sum of the values of the pixels corresponding to the ones included in the flux summation. If the `GAIN` value is not equal to -1, a term is added resulting in

$$\sigma_{obj} = \sqrt{\sum_{pixels} v^2_{RMS,obj} + f_{obj}/\mathrm{GAIN}}. \qquad (2)$$

If the option `replacepix` is set to `True` in the parameter file, the pixels within the aperture under analysis which are suspected of being contaminated by flux coming from other sources (i.e., which either are assigned to another object in the segmentation map, or are flagged as bad pixels, or have RMS value larger than a tolerance threshold) have their value replaced by the value

[2] A pixel x, y is considered to be within an elliptical Kron aperture of the object centered in x_0, y_0 if

$$x_1^2/a^2 + y_1^2/b^2 < 1, \qquad (1)$$

where $x_1 = (x - x_0) \times \cos(\mathrm{THETA\_IMAGE}) + (y - y_0) \times \sin(\mathrm{THETA\_IMAGE})$ and $y_1 = -(x - x_0) \times \sin(\mathrm{THETA\_IMAGE}) + (y - y_0) \times \cos(\mathrm{THETA\_IMAGE})$.

of the pixels symmetric to them with respect to the centroid of the source[3]. In case the keyword is set to `False`, those pixels are simply not included in the summations.

Since in some unfortunate cases the flux fluctuations around objects could include unphysically negative spots, a "clipping" option is included. When switched on, only the pixels having values above $-min(\sigma_{RMS}, \sigma_{bkgd})$ are included in the summation (where σ_{RMS} is the value of the pixel in the RMS map, and σ_{bkgd} is the standard deviation of the distribution of pixel values in the region where the background is computed, see Section 6.

6 Background estimation

A-PHOT can compute a local background estimation, writing background-subtracted fluxes in the output catalogue. To switch on this option, set to `True` the value of the keyword `bkgd` in the configuration file.

To estimate the background, A-PHOT computes the mean value of the pixels (i) outside $r_{bkgd} = f_{rbkgd} \times r_{Kron}$, (ii) within $r_{bkgd} + r_{buf}$px, excluding (iii) the ones belonging *to the considered object* according to the segmentation map (if given), and (iv) those with a value f so that $|f - f_{median}| < q_1 \times \sigma$, where σ is the value of the pixel in the RMS map. Furthermore, this mean is re-computed with a clipping procedure, excluding the pixels deviating from the median for more than $q_2\sigma$. Default values are set to $f_{rbkgd} = 1.2$, $r_{buf} = 10$px, $q_1 = 1.5$, $q_2 = 3.0$; they can be changed in the parameterfile. If the number pixels gathered this way is below a threshold $n_{min} = 0.25 \times A$ (where A is the area of ring in which the background is evaluated), the value of q_2 is iteratively increased until the threshold is reached. As in SEXTRACTOR, if the final value of the median after these iterations is varied by less than 20% wth respect to the initial one, it is assumed that the background is fairly flat and the mean value of the clipped pixel is taken as the background flux; otherwise, the expression $2.5 \times f_{median} - 1.5 \times f_{mean}$ is used.

Note that the two options "clipping" and "background subtraction" are independent from one another, i.e. they can be switched on and off separately.

7 Internal evaluation of morphological parameters

A-PHOT can compute some morphological parameters internally. Namely, the semi-axis a and b lengths (and hence the ellipticity and/or elongation), and the position angle (the inclination of the major semi-axis with respect to the X-axis of the image or of the equatorial plane, measured counter-clockwise), can

[3] If the source is at the border of the image, so that the symmetric pixel would be outside the borders, the substitution is made with an axial rather than central symmetry, if possible; if this is not possible either, the pixel is flagged out.

be determined after computing the second moments of the light distribution summing on all the significative pixels.

To use this option, the major semi-axis a must have negative value in the input catalogue. The value will be interpreted as the radius within which A-PHOT will compute the parameters.

The second moments of the light distribution are computed on the pixels belonging to the segmentated area of the sources. At present, A-PHOT cannot compute moments without a segmentation map[4].

Second moments are computed (like in SEXTRACTOR) as:

$$\begin{aligned}
\bar{x} &= \sum f \times x / \sum f; \\
\bar{y} &= \sum f \times y / \sum f; \\
\overline{x^2} &= \sum f \times x^2 / \sum f - \bar{x}^2; \\
\overline{y^2} &= \sum f \times y^2 / \sum f - \bar{y}^2; \\
\overline{xy} &= \sum f \times x \times y / \sum f - \bar{x}\bar{y}.
\end{aligned}$$

where f is the value of each pixel and the summation is performed including the pixels within a circular region centered on the input coordinates of the centroid of each source and satysifing the above-mentioned conditions.

From these equations, the values of the semi-axes a, b and of the position angle θ can be obtained from

$$a = \sqrt{(\overline{x^2} + \overline{y^2})/2 + \sqrt{[(\overline{x^2} - \overline{y^2})/2]^2 + \overline{xy}^2}}; \quad (3)$$

$$b = \sqrt{(\overline{x^2} + \overline{y^2})/2 - \sqrt{[(\overline{x^2} - \overline{y^2})/2]^2 + \overline{xy}^2}}; \quad (4)$$

$$\tan(2\theta) = 2 \times \overline{xy} / (\overline{x^2} + \overline{y^2}). \quad (5)$$

If these parameters are given as external input, or once they have been computed internally, the Kron radius of the object is obtained summing on a circular region of radius $6 \times a$, as

$$R_1 = \sum r \times f / \sum f, \quad (6)$$

The elliptical aperture magnitudes ("Kron magnitudes", correspoding to SEXTRACTOR `MAG_AUTO`) are then computed within the elliptical area with major semi-axis $R_1' = 2.5 \times R_1$. Minimum and maximum values for R_1' must be given in input (as multiplicative factors for the semi-axis a). Tests on simulated

[4]A tentative version is in progress, in which A-PHOT uses all pixels above $q_{sigma} = 1.0$ (considering the r.m.s. map values) and within the input searching radius; to exclude contamination from local noise fluctuation, a pixel is included in the summation only if the sum of the values of a square of 5×5 pixels centered on it is above the sum of the corresponding r.m.s. pixels values.

images have shown that imposing a minimum value of $R'_{1,min} = 8 \times a$ and a maximum value of $R'_{1,max} = 20 \times a$ generally yields good results, minimizing the systematic offset in the measured fluxes with respect to the input "true" values and reducing the standard deviation of the distribution. Note that the default value for $R'_{1,min}$ in SExtractor is 3.5.

If background subtraction is performed, the pixels values must be considered *after* such subtraction. To this aim, a double loop is done, following this conceptual scheme: (i) a first guess of the Kron radius is obtained from the original image (i.e. not background subtracted); (ii) such radius is used to select the region in which a first background estimation is performed; (iii) a second estimate of the Kron radius is then made, using the background subtracted values of the pixels; (iv) a new background subtraction is made using such Kron radius estimate.