

# Aperture Photometry Tool

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Aperture Photometry Tool (APT) is software for astronomers interested in manually exploring the photometric qualities of astronomical images. It is a graphical user interface (GUI) designed to allow aperture-photometry calculations to be visualized. The finely tuned layout of the GUI, along with judicious use of color coding and alerting, is intended to give maximal user utility and convenience and minimal chance of blunders. Simply clicking on a source in the displayed image will instantly compute and print out source intensity and noise, along with both non-robust and robust measures of the sky background and noise. APT is geared toward processing sources in a small number of images, and is not suitable for bulk processing a large number of images, unlike other aperture-photometry packages (e.g., SExtractor). However, APT does have a convenient source-list tool that enables aperture-photometry calculations for a large number of detections in a given image. The source-list tool can be run either in automatic mode to quickly generate a photometry table, or in manual mode to permit inspection and adjustment of the aperture-photometry calculation for each individual detection. APT displays a variety of useful plots with just the push of a button, including image histogram, aperture slice, source scatter, sky scatter, sky histogram, radial profile, and curve of growth. APT has many functions for customizing aperture-photometry calculations, including outlier rejection, pixel “picking” and “zapping”, and a selection of source and sky models. The radial-profile-interpolation source model, which is accessed via the radial-profile-plot panel, allows recovery of flux density in pixels with missing data, and can be especially beneficial in crowded fields. APT’s results are in excellent agreement with similar output from SExtractor.

Keywords: Data analysis, Aperture photometry, Aperture Photometry Tool (APT), Astronomical software, Source intensity, Source noise, Sky background, Graphical user interface, SExtractor, Palomar Transient Factory (PTF)

## I. INTRODUCTION

This paper introduces new software called Aperture Photometry Tool (APT) and gives many details about how to use it and how it works. The intent of the software is to make aperture photometry easy and fun through an intuitive graphical user interface (GUI), as shown in Figure 13. The software enables aperture photometry to be performed interactively and gives visual feedback in various ways to facilitate calculational refinement. APT is meant to complement, rather than supplant, popular non-interactive (batch-mode) aperture-photometry software, such as the increasingly popular SExtractor [1].

The initial beta version of APT was released in November of 2007, and, since that time, there have been many releases of the package to add new capabilities and fix bugs. APT is available, free of charge to anyone, from

<http://spider.ipac.caltech.edu/staff/laher/apt>

This URL has download/installation instructions for a variety of computer operating systems, including, but not limited to, Mac OS X, Linux, Windows and Solaris.

APT is an all-Java software implementation. There are no software dependencies on other astronomical packages or libraries. However, you will need to have a recent version of the Java Runtime Environment (JRE) installed on your machine. Version 1.0.0 of APT was compiled with javac 1.5.0\_16.

APT’s minimum memory requirement is probably around 4 MBytes. APT can be used on machines with relatively small memories to analyze portions of very large images, which is effected by setting the maximum image size under APT’s “Preferences” menu to as little as 500 pixels on a side.

The layout of this paper is as follows. Section II gives basic APT usage instructions for users wanting a quick start. Section III explains how APT does sky-background estimation and the available options for controlling it.

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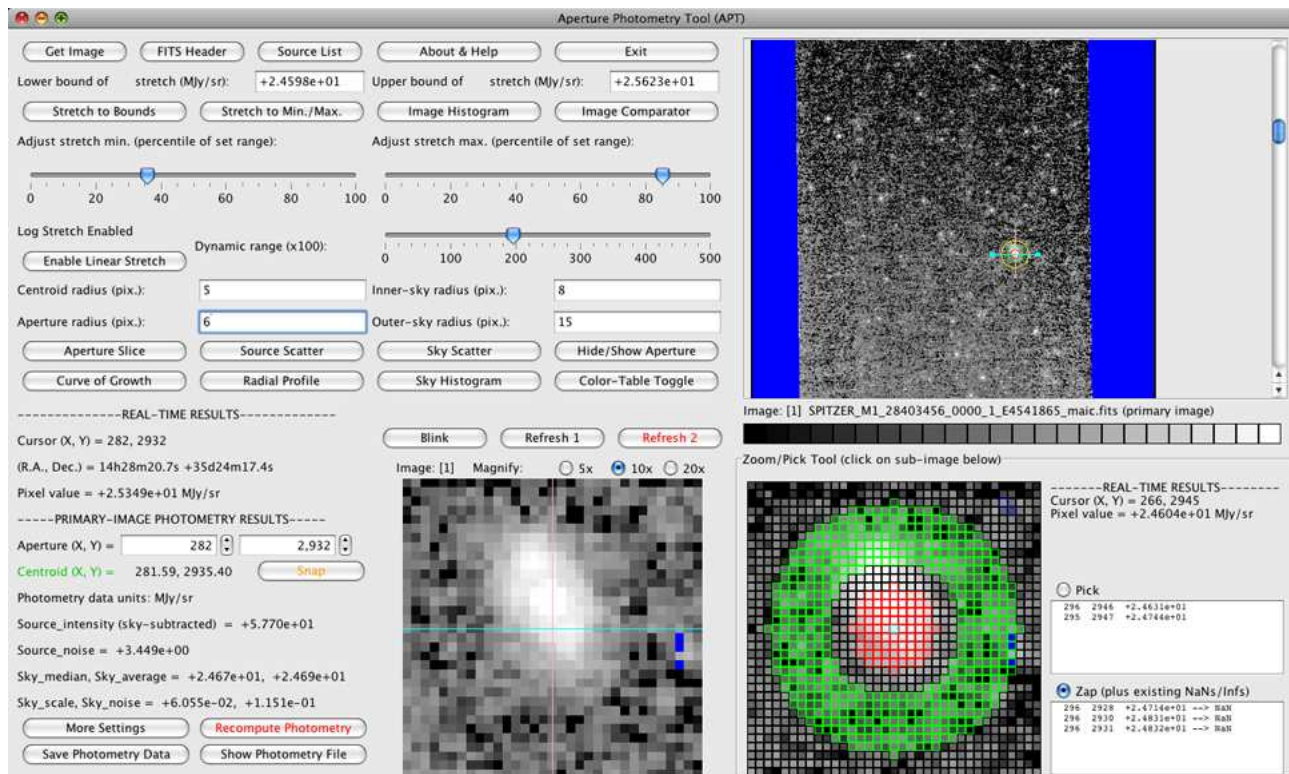


FIG. 1: Main GUI panel of APT.

Section IV provides details on how APT does aperture-photometry calculations and what options are available for refining it. Section V, by way of furnishing indispensable non-patent information, relates crucial miscellaneous APT features and behaviors. Subsequent sections discuss APT’s salient components, functions and functionality: user preferences, output files, columns in output photometry table, graphs, radial-profile interpolation, zoom/pick tool, source-list tool, image comparator and blink capability, software limitations, and troubleshooting and bug reporting. The paper crescendoes with a quantitative comparison of similar calculational results from SExtractor and APT, and, finally, resolves with a concluding section.

## II. BASIC USAGE INSTRUCTIONS

APT is simple to use. Basically, you display a FITS image and then mouse click on a source (or astronomical object) in the image to overlay a circular aperture on it. The latter action causes the software to automatically compute source-centroid position, source intensity, source noise, sky-background level and sky-background noise. The default sky algorithm is no sky-background subtraction from the source intensity, and the reason for this is to facilitate proper use of APT’s radial-profile interpolation capability. More often than not, however, the user will require the sky background to be subtracted

from the source intensity, in which case, this can be selected from the control panel that pops up after clicking on the “More Settings” button (located at the bottom-left corner of the main GUI panel). See Figure 2 for a depiction of the “More Settings” panel.

The general flow of the work progresses from the buttons and controls at the top-left corner of the main GUI panel to the middle-left region and then bottom-left region of the same. Here are the basic instructions.

1. Take a moment to review the default settings by selecting “List Preferences” from the “Preferences” menu. More information on user preferences is given in Section VI.
2. Choose a primary image to display by mouse-clicking on the “Get Image” button in the upper-left corner of the GUI panel. APT only reads in FITS-formatted images, the image format commonly adopted by astronomers [2]. A primary image is, by definition, the first image displayed in the upper right image-viewing panel.
3. Adjust image stretch for best viewing. As an aid, click on the “Image Histogram” button to see the stretch range spanned by the image.
4. Select centroiding, aperture, and sky-annulus radii (integer values only), as appropriate for the source of interest.

Select source algorithm:	<input checked="" type="radio"/> Model 0 = No aperture interpolation <input type="radio"/> Model 1 = Interpolation only for NaN/Inf pixels <input type="radio"/> Model 2 = Interpolation for all aperture pixels
Select sky algorithm:	<input checked="" type="radio"/> Model A = No sky subtraction <input type="radio"/> Model B = Sky-median subtraction <input type="radio"/> Model C = Custom sky subtraction (below) <input type="radio"/> Model D = Sky-average subtraction
Custom sky value (D.N.):	<input type="text" value="0.00000e+00"/>
Use centroid in photometry calculation?	<input checked="" type="checkbox"/>
Reject source values (D.N.) less than:	<input type="text" value="-1.79769e+308"/>
Reject source values (D.N.) greater than:	<input type="text" value="1.79769e+308"/>
Reject sky values (D.N.) less than:	<input type="text" value="-1.79769e+308"/>
Reject sky values (D.N.) greater than:	<input type="text" value="1.79769e+308"/>
BUNIT:	N/A
Default image-data title:	<input type="text" value="Surface brightness"/>
Gain (electrons per D.N.):	<input type="text" value="1.5000000e+00"/>
Image-data-to-D.N. conversion factor:	<input type="text" value="1.0000000e+00"/>
Perform new image-data conversion (see settings below)?	<input type="checkbox"/>
New image-data conversion factor:	<input type="text" value="1.0153728e-01"/>
Image-data units after new conversion:	<input type="text" value="Jy"/>
Image-data title after new conversion:	<input type="text" value="Flux density"/>
<input type="button" value="Apply Settings"/> <input type="button" value="Close Window"/>	

FIG. 2: “More Settings” panel of APT.

5. Place mouse cursor over source of interest in image displayed in upper-right image-viewing panel and click to overlay an aperture.
6. Show/study the various graphs (instructions are given in Section IX below).
7. Select desired new radii and/or change other settings as needed.
8. Redraw/overlay new aperture by either clicking on “Recompute Photometry” button OR clicking on “Snap” button for nudging the aperture toward the integer pixel coordinates of the source-centroid location OR placing mouse cursor on image and clicking.
9. If necessary, increment/decrement aperture position using the spinner controls for fine tuning the aperture’s position.
10. Click on “Recompute Photometry” button to redraw/overlay new aperture.
11. Show/study the various graphs again.
12. Optionally click on “Save Photometry Data” button to save/append the results to APT’s output photometry-table file (e.g., APT.tbl).
13. Repeat above steps for each source of interest!

### III. SKY-BACKGROUND ESTIMATION

APT uses fairly straightforward methods for estimating the sky background in the region local to the source of interest, and there are a few options available for controlling how it is done. Only image pixels in a sky annulus centered on a selected center position are used in the background calculation. The center position for purposes of background estimation is specified in integer pixels only. There are three ways to specify the center position:

1. Mouse-clicking on the image displayed in upper-right image-viewing panel;
2. Adjusting the spinner controls in the lower-left main GUI panel; or

3. Clicking on the “Snap” button in the lower-left main GUI panel (more on this in Section IV below).

The inner and outer radii of the sky annulus, in integer pixels only, can be specified on the main GUI panel.

On the control panel that pops up after clicking on the “More Settings” button, the user can select from one of four available sky algorithms:

1. No background subtraction;
2. Sky-median subtraction;
3. Custom-sky subtraction; or
4. Sky-mean subtraction.

Only sky-median subtraction is insensitive to other sources that may fall within the sky annulus, which might otherwise cause the background to be overestimated. According to Bertin and Arnouts [1], strictly speaking, the background includes everything but the source in the reticle of the aperture. As a practical matter, we estimate the background in the aperture from the sky annulus that surrounds it. An intense source in the sky annulus contributes to the background in the aperture, and its effect is not necessarily something that is to be completely ignored or filtered out, which is why APT has a variety of sky models from which to choose.

The “More Settings” panel also has text fields where the user can optionally specify lower and upper thresholds for rejection of outlier pixels in the sky annulus from the background calculation. The default values for the lower and upper thresholds are the largest possible negative and positive double-precision numbers, respectively, so that, by default, no pixels are rejected. Values for outlier-rejection thresholds must be given in image data units. It is best to show/study the various graphs and set these thresholds before converting image data units to desired source-intensity units (via “Perform image-data conversion” checkbox on the “More Settings” panel – more on this in Section IX below).

The pixel “zap” functionality of the zoom/pick tool can also be used to temporarily eliminate pixels from the background calculation. More details about the zoom/pick tool are given in Section XI below.

#### IV. APERTURE PHOTOMETRY

The aperture-photometry calculation primarily results in source intensity and source noise. The former involves summing of pixel values within the aperture to get the total intensity and subtracting off the product of the aperture area and per-pixel sky background. The latter requires extra information, including detector gain, aperture geometry, sky-annulus geometry, background-estimation method, and sky noise. APT works under the

assumption that the background is constant across the aperture.

Version 1.0.0 of APT only performs aperture-photometry calculations with circular apertures. It is not inconceivable that later versions of APT will have options for other types of aperture-photometry calculations (e.g., SExtractor’s isophotal, and Petrosian-like and Kron-like elliptical aperture options).

Basic inputs for the aperture-photometry calculation are aperture radius, source-centroid radius (calculation of the source’s centroid position can involve fewer or more pixels than in the aperture-photometry calculation), and a selected center position (instructions for doing this are given in Section III above). The aperture and centroid radii, in integer pixels only, can be specified on the main GUI panel.

The “More Settings” panel has text fields where the user can optionally specify lower and upper thresholds for rejection of spurious aperture pixels in the aperture-photometry calculation. The default values for the lower and upper thresholds are the largest possible negative and positive double-precision numbers, respectively, so that, by default, no pixels are rejected. Again, values for outlier-rejection thresholds must be given in image data units.

The pixel “zap” functionality of the zoom/pick tool can also be used to temporarily eliminate pixels from the aperture-photometry calculation. More details about the zoom/pick tool are given in Section XI below.

The “More Settings” panel also has radio buttons for the user to select from one of three available source algorithms:

1. No aperture interpolation;
2. Aperture interpolation only for NaN or Inf pixels (including “zapped” pixels); or
3. Interpolation only for all aperture pixels.

(Note that “NaN” stands for not a number, and Inf stands for infinity.)

The aperture-photometry calculation is done with sub-pixel resolution. The default sub-pixel size is 0.01 pixels, which can cause the computations to take several seconds for very large centroid, aperture and/or sky-annulus radii. The sub-pixel size can be changed via the “Preferences” menu.

By default, the aperture-photometry calculation is performed with the aperture centered on the calculated centroid, to the resolution given by the sub-pixel size. The “Centroid (X, Y) =” label on the lower-left of the main GUI panel is displayed in a green color to indicate that centroiding is enabled. Un-checking the “Use centroid in photometry calculation?” check box on the “More Settings” panel will cause the photometry calculation to revert to centering the aperture on the integer pixel coordinates of the selected aperture position and be performed on whole pixels only. The “More Settings” panel

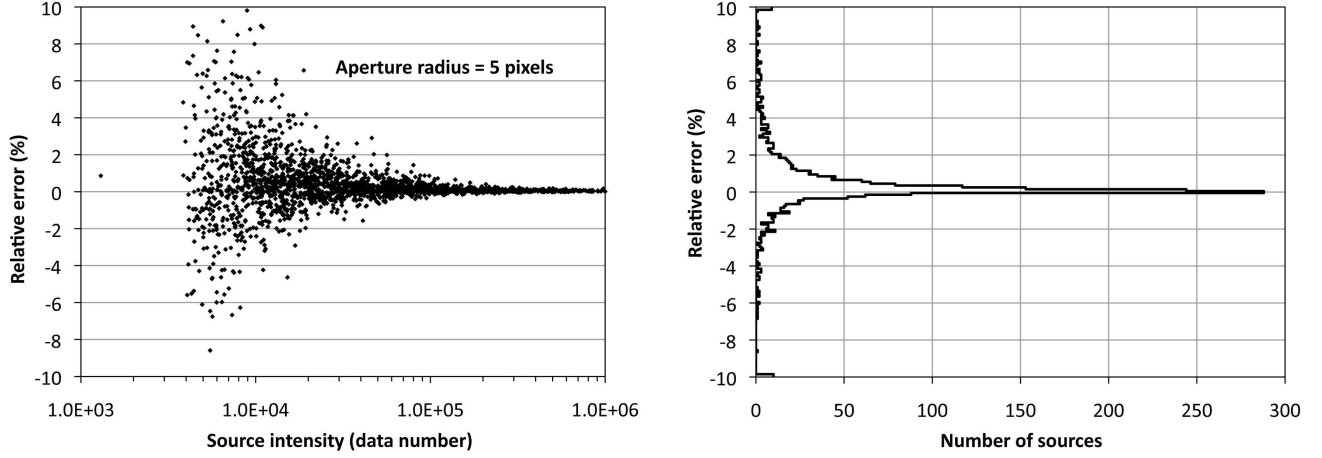


FIG. 14: Comparison of source intensity computed by APT vs. SExtractor for case #1. The left panel is a scatter plot of the relative percentage error between SExtractor and APT as a function of source intensity for the 2,069 filtered sources from PTF image *PTF200912013273\_2\_o\_1997* (CCDID=8). The right panel is a histogram of the relative percentage errors for all case-#1 filtered sources.

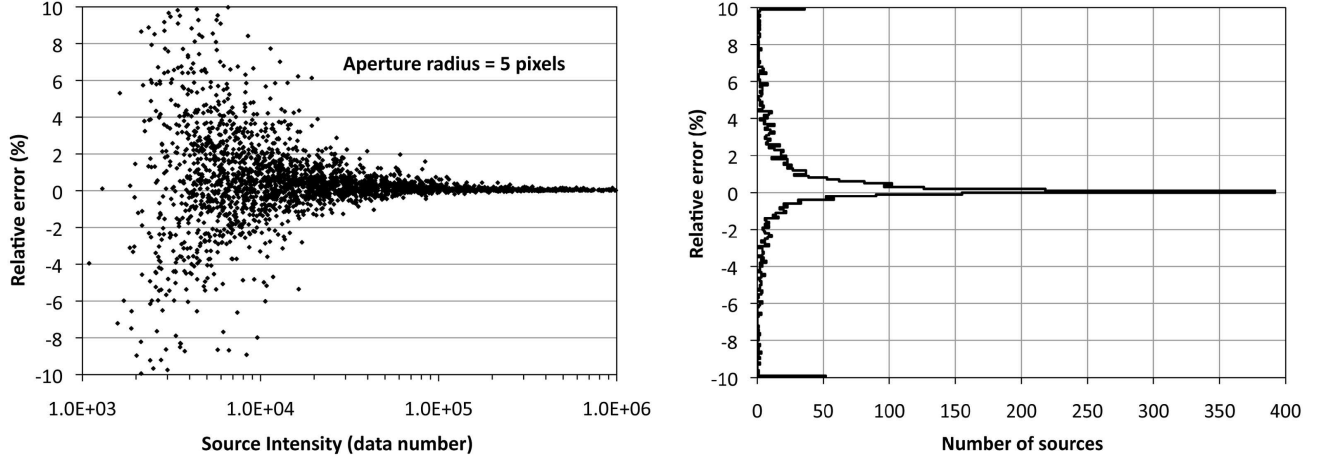


FIG. 15: Comparison of source intensity computed by APT vs. SExtractor for case #2. The left panel is a scatter plot of the relative percentage error between SExtractor and APT as a function of source intensity for the 2,653 filtered sources from PTF image *PTF200912015481\_2\_o\_2116* (CCDID=8). The right panel is a histogram of the relative percentage errors for all case-#2 filtered sources.

filtered sources of cases #1 and #2 are shown. The top panels are scatter plots of the source-noise relative percentage error between SExtractor and APT as a function of source intensity, which have median values of  $-2.73\%$  for case #1 and  $-2.48\%$  for case #2. As might be expected, the larger discrepancy occurs for case #1, which has the higher background of the two cases. The negative values indicate that APT overestimates the source noise relative to SExtractor, which may not be a surprising result because APT includes the uncertainty of the background estimation; whereas SExtractor does not, according to [3]. Moreover, a comparable plot of SExtractor's FLUXERR versus FLUX results in a locus of data points that fairly smoothly follows the lower edge of

the scattered APT data points, which is in conformance with the statement that SExtractor's source-noise estimate can only be regarded as a lower limit [3]. Our crude simulations of folding the uncertainty of the background estimation into SExtractor's source-noise values improve the aforementioned median values of the source-noise relative percentage error to about  $-1\%$  for both cases. The middle panels are scatter plots of the source-noise relative percentage error between SExtractor and APT as a function of sky noise. As defined in Section VIII, the sky noise is the standard deviation of samples in the sky annulus after the sky outliers have been rejected (there were none rejected in cases #1 and #2, since APT's source-list tool was run in automated mode, and APT has no  $N\sigma$  outlier-

rejection capability, yet; APT only has outlier rejection whose lower and upper thresholds must be explicitly set). One can start to see a dependence of source-noise relative percentage error on sky noise. This is even more apparent in the bottom panels, which are scatter plots of the source-noise relative percentage error between SExtractor and APT as a function of sky scale. The sky scale, also defined in Section VIII, is a robust estimator of the sky noise, and comparing the middle and bottom panels demonstrates how the sky scale is a representation of source noise that is mostly “collapsed” horizontally onto a line along the obvious lower-range leading edge of the data points (the slope of the line formed by the data in the bottom panel is the same as the lower-range leading edge of the data in the corresponding middle panel, which is not readily seen because the horizontal axes have different scales). Thus, it can now be easily seen that the discrepancy in source-noise estimates between APT and SExtractor increases with increasing sky scale. It is unclear whether this effect can be attributed to the uncertainty in background estimation, rather than to the background estimation itself. The devil is in the details, but further investigation is beyond the scope of this paper.

## XVII. CONCLUSION

We have introduced important new software for the astronomical community that facilitates the visualization of aperture photometry. APT is appropriate, useful and convenient for professional work, and it is also now playing a vital role in educating the next generation of astronomers in the United States. It has been successfully utilized in the past Spitzer Teachers program, and will be the centerpiece of the newly formed NASA-IPAC Archive Teacher Research Project (NITARP). There are indubitably many reasons that give APT a purpose in today’s world, and chief among them are its graphical

user interface and feedback, machine independence, ease of installation and use, and accuracy. The latter was clearly demonstrated here by comparing similar results between SExtractor and APT. It is expected that APT will be upgraded over time to shake out any remaining bugs and augment the software with new functionality and capabilities.

## Acknowledgments

APT requires the following packages: JFreeChart ([www.jfree.org](http://www.jfree.org)), JRegEx ([jregex.sourceforge.net](http://jregex.sourceforge.net)), and Jama ([math.nist.gov/javanumerics/jama](http://math.nist.gov/javanumerics/jama)), plus a handful of the Spitzer Spot/Leopard Java classes for astrometry. These come packaged with APT, and so the user need not install them separately.

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- [1] E. Bertin and S. Arnouts, *Astronomy and Astrophysics Supp. Ser.* **117**, 393 (1996).
  - [2] D. C. Wells, E. W. Greisen, and R. H. Harten, *Astronomy and Astrophysics Supp. Ser.* **44**, 363 (1981).
  - [3] E. Bertin, *SExtractor, v. 2.5, User’s Manual* (Institut d’Astrophysique & Observatoire de Paris, 2006).
  - [4] F. Masci and R. R. Laher, *PASP manuscript in preparation* (2010).
  - [5] N. M. Law, S. R. Kulkarni, R. G. Dekany, E. O. Ofek, R. M. Quimby, P. E. Nugent, J. Surace, C. C. Grillmair, J. S. Bloom, M. M. Kasliwal, et al., *PASP* **121**, 1395 (2009).
  - [6] B. W. Holwerda, *Source Extractor for Dummies* (Space Telescope Science Institute, 2005), 5th ed.

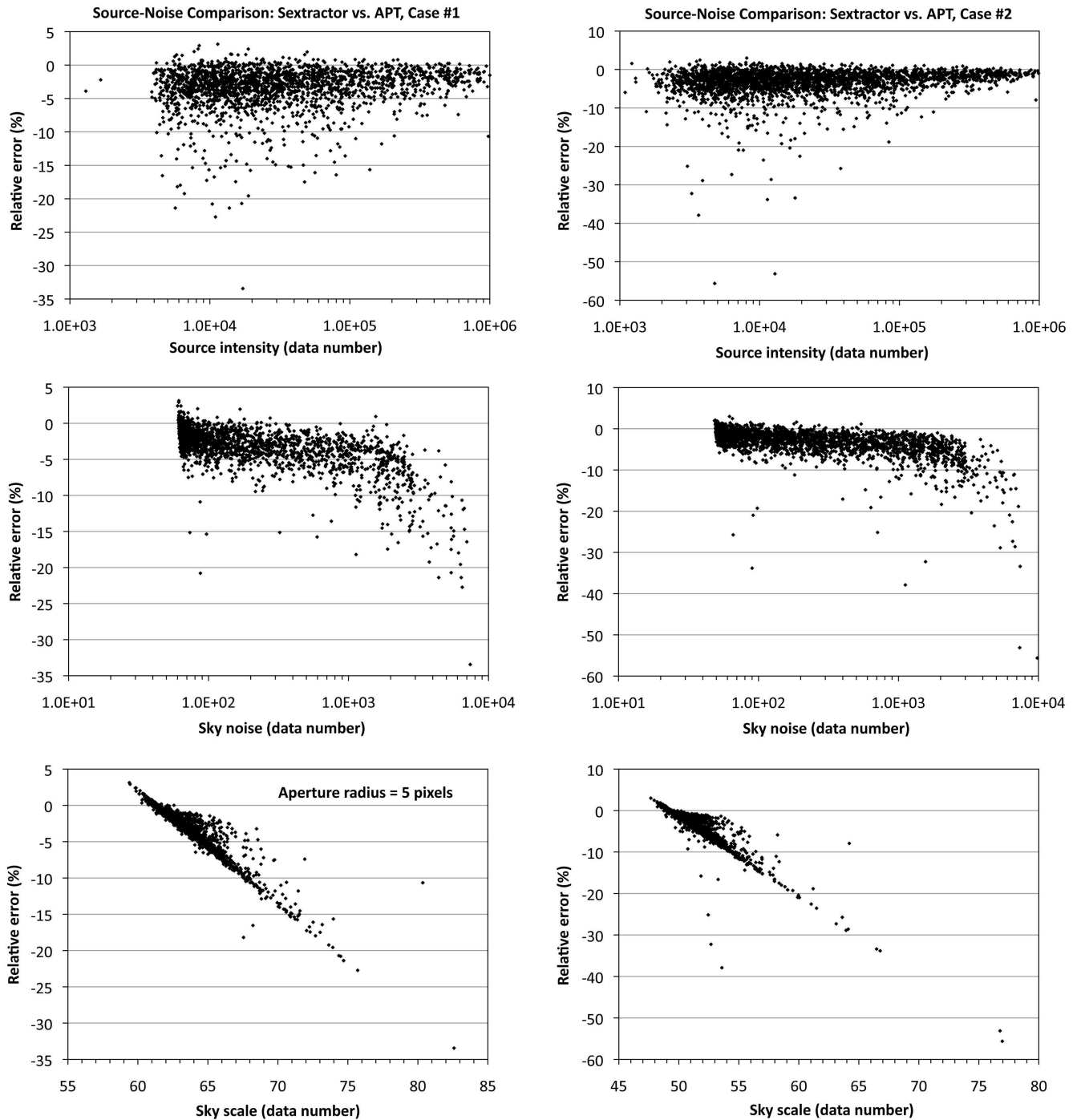


FIG. 16: Comparison of source noise computed by APT vs. SExtractor for cases #1 (left) and #2 (right). The top panels are scatter plots of the relative percentage error between SExtractor and APT versus source intensity. The middle panels are scatter plots of the relative percentage error between SExtractor and APT versus sky noise. The bottom panels are scatter plots of the relative percentage error between SExtractor and APT versus sky scale.