PS1 Forced photometry of sources

Forced Photometry refers to photometric measurements conducted at a specified location. It is "forced" in order to extract a magnitude or magnitude limit at a sky location where an explicit source detection exists in another filter band.

Contents

The starting point for the PS1 data archive is at Pan-STARRS1 data archive home page.

Traditionally, projects which use multiple exposures to increase the depth and sensitivity of the observations have generated something equivalent to the PS1 Stack images produced by the IPP pipeline. In principle, extracting photometry from the stack images produces the best and most reliable data overall. The stack images have the best signal-to-noise and thus the best sensitivity and the best data quality at all magnitudes (c.f, CFHT Legacy survey, COSMOS, etc). However, in practice the stack images have some significant limitations due to the difficulty of modeling the inevitable PSF variations from one image to the next. This difficulty is particularly severe for the PS1 3PI survey stacks due to the combination of the substantial mask fraction of the individual exposures, the large intrinsic image quality variations within a single exposure, and the wide range of image quality conditions under which data were obtained and used to generate the 3PI PV3 stacks.

For any specific stack image, the PSF (point spread function) at a particular location is the result of the combination of the point spread functions for those individual exposures which went into the stack at that point. Because of the high mask fraction (i.e., the fraction of pixels excluded from use in a given image; see PS1 Mask image), the exposures which contributed to pixels at one location may be somewhat different just a few tens of pixels away. Because of the intrinsic variations in the PSF across an exposure and because of the variations from exposure to exposure, the distribution of point spread functions of the images used at one position may be quite different from those at a nearby location. In the end, the stack images have a effective point spread function which is not just variable, but changing significantly on small scales in a highly textured fashion. The apparent improvement in signal-to-noise comes at a price.

Any measurement which relies on a good knowledge of the PSF at the location of an object will be degraded unless one can determine the PSF variations present in the stack. The highly textured PSF variations make this a very challenging problem: one could apply a fine-grained PSF model, but there would likely not be enough PSF stars in a given stack image to determine the model at the resolution required. The PS1 IPP pipeline photometry analysis code uses a PSF model with 2D variations using a grid of at most 6 × 6 samples per skycell, a number reasonably well-matched to the density of stars at most Galactic latitudes. But this scale is far too large to track the fine-grained changes apparent in the stack images. Thus PSF photometry, as well as convolved Galaxy models in the stack, are degraded by the PSF variations. Aperture-like measurements are in general not as affected by the PSF variations, as long as the aperture in question is large compared to the size of the PSF. The 3pi analysis solves this problem by using the sources detected in the stack images and performing forced photometry on the individual warp images used to generate the stack. This analysis is performed on all warps for a single filter as a single job, though this is more of a bookkeeping aid as it is not necessary for the analysis of the different warps to know about the results of the other warps. In the forced warp photometry, the positions of sources are loaded from the stack outputs. PSF stars are selected and a PSF model generated for each warp based on those stars, using the same stars for all warps to the extent possible (PSF stars which are excessively masked on a particular image are not used to model the PSF). The PSF model is fitted to all of the known source positions in the warp images. Aperture magnitudes, Kron magnitudes, and moments are also measured at this stage for each warp. Note that the flux measurement for a faint, but significant, source from the stack image may be at a low significance (< 5) in any individual warp image; the flux may even be negative for specific warps. When combined together, these low-significance measurements will result in a significant measurement because the signal-to-noise increases by N.

Forced galaxy model fitting

The convolved galaxy models are also re-measured on the warp images in the **forced photometry** analysis stage. In this analysis, the galaxy models determined by the stack photometry analysis are used to seed the analysis in the individual warps. The purpose of this analysis is the same as the forced PSF photometry: the PSF of the stack is poorly determined due to the masking and PSF variations in the inputs. Without a good PSF model, the PSF-convolved galaxy models are of limited accuracy. In the forced galaxy model analysis, we assume that the galaxy position and position angle, along with the Sersic index, if appropriate, have been sufficiently well determined in the stack analysis. In this case, the goal is to determine the best values for the major and minor axes of the elliptical contour and at the same time the best normalization corresponding to the best elliptical shape (and thus the best galaxy magnitude value). For each warp image, the Stack value for the major and minor axes are used as the center of a 7×7 grid search of the major and minor axis parameter values. The grid spacing is defined as a function of the signal-to-noise of the galaxy in the stack image so that bright galaxies are measured with a much finer grid spacing that faint galaxies. For each grid point, the major and minor axis values at that point are determined for the model. The model is then generated and convolved with the PSF model for the warp image at that point. The resulting model is then compared to the warp pixel data values and the best fit normalization value is defined. The normalization and the chi-squared value for each grid point is recorded.

For a given galaxy, the result is a collection of chi-squared values for each of the grid points spanning all warp images. A single chi-squared grid can then be made from all warps by combining each grid point across the warps. The combined chi-squared for a single grid point is simply the sum of all chi-squared va lues at that point. If, for a single warp image, the galaxy model is excessively masked, then that image will be dropped for all grid points for that galaxy. The reduced chi-squared values can be determined by tracking the total number of warp pixels used across all warps to generate the combined chi-squared valu es. From the combined grid of chi-squared values, the point in the grid with the minimum chi-squared is found. Quadratic interpolation is used to determine the major, minor axis values for the interpolated minimum chi-squared value. The errors on these two parameters is then found by determining the contour at which the reduced chi-squared increases by 1. Thus the Forced Galaxy Model analysis uses the PSF information from each warp to determine a best set of convovled galaxy models for each object in the stack images.

Data tables with forced photometry from PS1 Warp images

Note: Forced photometry from warp images is available in DR2.

- **PS1 ForcedWarpMeasurement table fields**: Contains single epoch forced photometry of individual measurements of objects detected in the stacked images. The identifiers connecting the measurement back to the original image and to the object association are provided. PSF, aperture, and Kron (1980) photometry are included, along with sky and detector coordinate positions. References: Kron, R. G. 1980, ApJS, 43, 305.
- **ForcedWarpExtended**: Contains the single epoch forced photometry fluxes within the SDSS R5 (r = 3.00 arcsec), R6 (r = 4.63 arcsec), and R7 (r = 7.43 arcsec) apertures (Stoughton 2002) for objects detected in the stacked images. References: Stoughton, C., Lupton, R. H., Bernardi, M., et al. 2002, AJ, 123, 485.
- **ForcedWarpLensing**: Contains the Kaiser et al. (1995) lensing parameters measured from the forced photometry of objects detected in stacked images on the individual single epoch data. References: Kaiser, N., Squires, G., and Broadhurst, T. 1995, ApJ, 449, 460.
- **ForcedGalaxyShape**: Contains the extended source galaxy shape parameters. All filters are matched into a single row. The positions, magnitudes, fluxes, and Sersic indices are inherited from their parent measurement in the StackModelFit tables, and are reproduced here for convenience. The major and minor axes and orientation are recalculated on a warp-by-warp basis from the best fit given these inherited properties. References: Sersic, J. L. 1963, Boletin de la Asociacion Argentina de Astronomia La Plata Argentina, 6, 41.
- **ForcedWarpMasked**: Contains an entry for objects detected in the stacked images which were in the footprint of a single epoch exposure, but for which there are no unmasked pixels at that epoch.

Data tables with mean forced photometry from PS1 Warp images (DR1)

Note: Mean forced photometry is available in DR1 and DR2 (although the DR2 tables were still being populated at the time of the release). The specific contents of each Table can be obtained from the linked pages.

- **ForcedMeanObject**: Contains the mean of single-epoch photometric information for sources detected in the stacked data, calculated as described in Magnier et al. (2013). The mean is calculated for detections associated into objects within a one arcsecond correlation radius. PSF, Kron (1980), and SDSS aperture R5 (r = 3.00 arcsec), R6 (r = 4.63 arcsec), and R7 (r = 7.43 arcsec) apertures (Stoughton 2002) magnitudes and statistics are listed for all filters. References: Kaiser, N., Squires, G., and Broadhurst, T. 1995, ApJ, 449, 460; Kron, R. G. 1980, ApJS, 43, 305; Magnier, E. A., Schlafly, E., Finkbeiner, D., et al. 2013, ApJS, 205, 20; Stoughton, C., Lupton, R. H., Bernardi, M., et al. 2002, AJ, 123, 485.

- **ForcedMeanLensing**: Contains the mean Kaiser et al. (1995) lensing parameters measured from the forced photometry of objects detected in stacked images on the individual single epoch data. References: Kaiser, N., Squires, G., and Broadhurst, T. 1995, ApJ, 449, 460.