Report on the performance of the HIPE SUSSEXtractor and DAOPHOT source extractors on real data

Document number: SPIRE-SUX-REP-003263

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12th May 2011

1 Introduction

This document is a test report, investigating the performance of the HIPE source extractors on observed *Herschel*–SPIRE data. The two source extractors in HIPE are implementations of the SUSSEXtractor algorithm [AD01] and of the DAOPHOT algorithm.

The purpose of this report is to recommend any improvements to the algorithms that should be undertaken in the light of actual observational behaviour. This will be done by

1. investigating the performance of the algorithms on extragalactic data, where confusion is significant.
2. investigating the performance on calibration sources, where the flux density of the observed source is known already.

1.1 Applicable Documents

AD01 Bayesian Methods of Astronomical Source Extraction, Savage & Oliver (2007), ApJ, 661, 1339

AD02 SPIRE-UCF-DOC-3168; Issue 6, 13 July 2010; SPIRE Photometer Flux Density Calibration

1.2 Build and images used for the tests

The HIPE source extractors were tested using continuous integration build 8.0.358.

For the tests, the following images were used:

1. For the tests on extragalactic data, images from observation 0x5000227E were used (HerMES Lockman-North). This is an extragalactic field, covering approximately 0.34 square degrees. The observation was taken in SPIRE nominal mode, cross-scanned, with seven repetitions. To these data were added a sparse grid of point sources, each with the same Gaussian profile, and with various flux densities between 1 and 4000 mJy. The sources were added to the timelines, prior to the map making, using `bendoSourceSubtract` version 0.5, by George Bendo. Throughout, the point sources are Gaussian with FWHM (18.15, 25.15, 36.3) arcsec for (PSW, PMW, PLW) respectively, with a Gaussian approximation used for the beam area. Figure 1 shows one of the images used.
2. For the tests on calibration sources, observations of Gamma Draconis were used, with a calibration applied by George Bendo, supplied in June 2010. 24 observations were used: (0x5000) 2135, 255C, 255D, 2A8D, 2A8E, 2C32, 2C33, 2D1D, 2D1F, 32BD-E, 32BF-C0, 32C1-2, 32C3-4, 32C7, 32C8, 39CE, 39CF, 4088, 4089, 465C, 465D, 465F, 489F, 48A0.

2 Method

2.1 Extragalactic data

The quality of the source extraction in extragalactic fields may be quantified in terms of the reliability (spurious sources), the completeness (probability of detecting a source) and the quality of the position and flux density measurements.

The procedure for measuring the completeness and flux density accuracy is as follows (see Smith et al., in preparation).

First the source catalogues are produced:

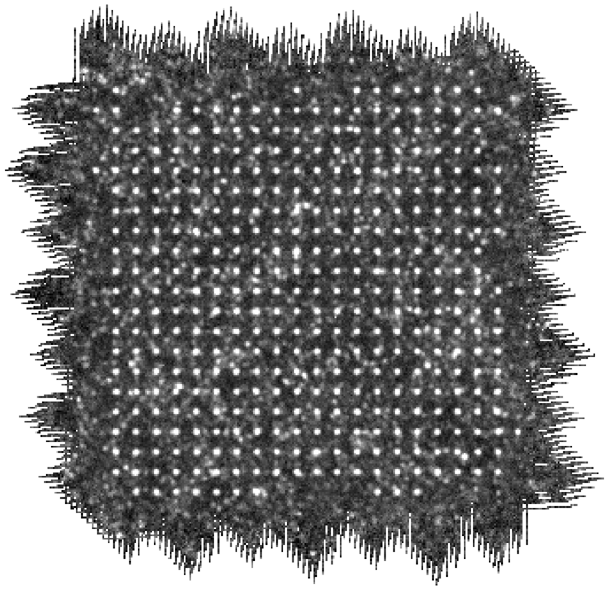

Figure 1: Lockman-North PMW image with grid of 100 mJy sources added.

1. The source extraction is performed on the map with no artificial sources added in order to define a **reference catalogue** for each band.

2. A **truth catalogue** is created, consisting of the grid of artificial sources, and this is used to create maps with injected sources, with all such sources having the same flux density. The whole procedure is repeated with each iteration having a different flux density for the injected sources. The flux densities chosen are 1, 2, 3, 4, 7, 10, 20, 30, 40, 70, 100, 200, 300, 400, 700, 1000 and 4000 mJy.

3. For each map with injected sources, the source extraction is performed, in exactly the same way as for the reference catalogue, to produce additional **source catalogues**, to be compared with the reference catalogues.

Next, with the reference catalogue, truth catalogue of artificial sources, and source catalogues for each injected flux density, the catalogues are compared as follows, for each band and for each injected flux density:

1. The artificial source truth catalogue is first cross-matched with the reference catalogue from the real data. For each source in the truth catalogue, the closest match within 1 times the FWHM is chosen (if such a source is present). If this match has a flux density within a factor of 2 of the injected source flux density, the match is identified as a 'good' match. Any such 'good' matches are discarded from further analysis; otherwise, when these (serendipitous) matches are included, the measured completeness can be misleading, particularly for source extraction methods that produce a large number of spurious, faint detections. However, excluding these sources will have a small effect on the estimates of the completeness, because part of the incompleteness comes from the fact that sources can be too close to other sources and therefore not counted.

2. Next the truth catalogue (without the serendipitous sources from the previous step) is cross-matched with the source catalogue derived from the map with injected sources. 'Good' matches are found, as above. The completeness is defined as the number of good matches divided by the number of injected sources (minus the serendipitous sources).

For example, if 200 sources with flux density 30 mJy are injected into the map, but 20 of those already (by chance) have 'good' counterparts in the original map (without injected sources), then the remaining number of sources is 180. If 162 of these have good matches in the source list extracted from the map with injected sources, then the completeness at 30 mJy is $162/180 = 90$ per cent.

3. The flux density and positional accuracy are found by comparing the extracted flux densities and positions with the injected flux densities and positions.

2.2 Calibration sources

For the calibration sources (Gamma Draconis), flux densities and positions are measured from multiple observations, and then compared for consistency with each other, and for consistency with the known flux density and position of the source.

3 Results for SUSSEXtractor

3.1 Extragalactic data with SUSSEXtractor

SUSSEXtractor was used with its default settings (no background fitting, and a Jeffreys prior for the flux). Over 0.34 square degrees, SUSSEXtractor makes (1066, 579, 255) detections in (PSW, PMW, PLW).

There was no evidence of spurious detections in the tests that were performed, insofar as all detections were clearly associated with astronomical flux (although both SUSSEXtractor and DAOPHOT are susceptible to glitches and blending of close pairs of sources).

Figure 2 shows the completeness, with 50% completeness being achieved at flux densities of (13.3, 15.3, 16.2) mJy for (PSW, PMW, PLW).

Figure 3 shows the flux density accuracy for the same data. At faint and intermediate injected flux densities, there are complex effects due to flux boosting and the zero mean in the maps. At injected flux densities brighter than 30 mJy, the behaviour is easier to understand, with higher precision for brighter injected sources. However, (1) there is a systematic offset in flux density, with the fluxes being underestimated by approximately 5%, and (2) there appears to be a trend to further underestimate the flux densities of very bright injected sources for PLW and PMW, with a mean offset of approximately 10%.

Figures 4 and 5 show the positional accuracy in right ascension and declination respectively for the same data. The behaviour is as expected, with higher precision for brighter injected sources. The standard deviation for the error in the position for 1 Jy injected sources is less than 1 arcsec in both directions for PLW and PMW and less than 0.5 arcsec for PSW.

3.2 Calibration sources with SUSSEXtractor

The observations listed in Section 1.2 were used to measure the flux of Gamma Draconis using SUSSEXtractor, with the same parameters as in the previous section. Measured fluxes and positions are shown in Figures 6–8.

The flux density of Gamma Draconis from [AD02] is modelled as (252, 128, 62) mJy in (PSW, PMW, PLW). With SUSSEXtractor, the median measured fluxes are (257.2, 131.6, 63.7), which are greater than the model fluxes by 2–3%.

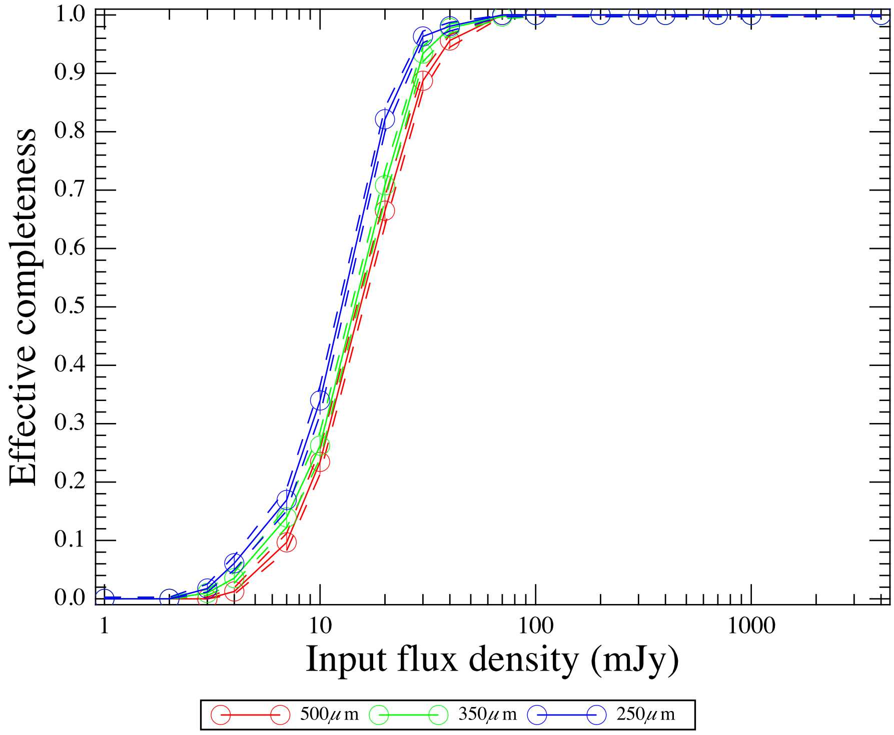

Figure 2: Completeness for SUSSEXtractor on the Lockman-North data.

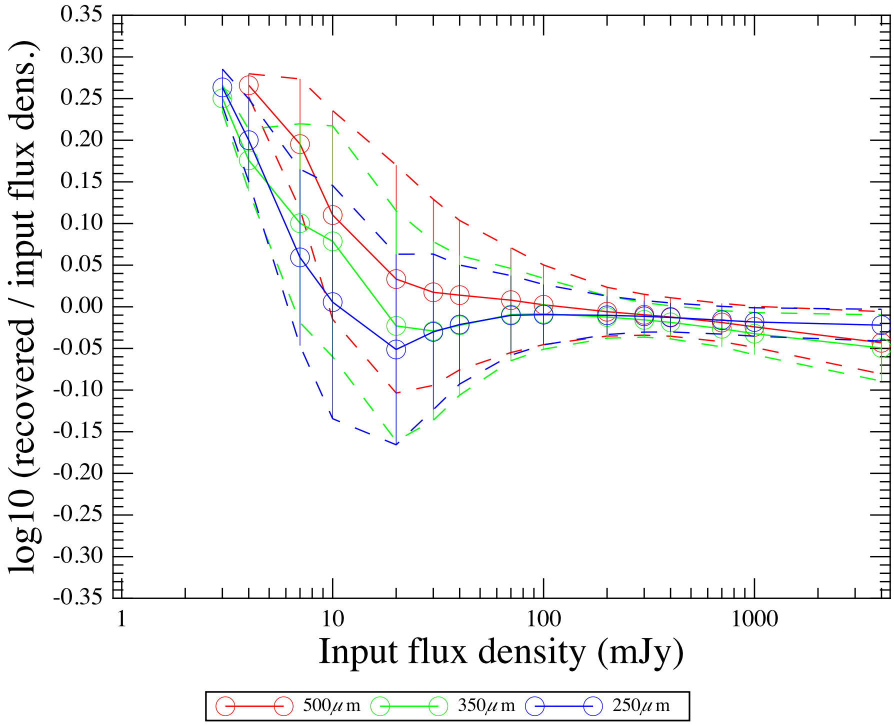

Figure 3: Accuracy of flux densities for SUSSEXtractor on the Lockman-North data.

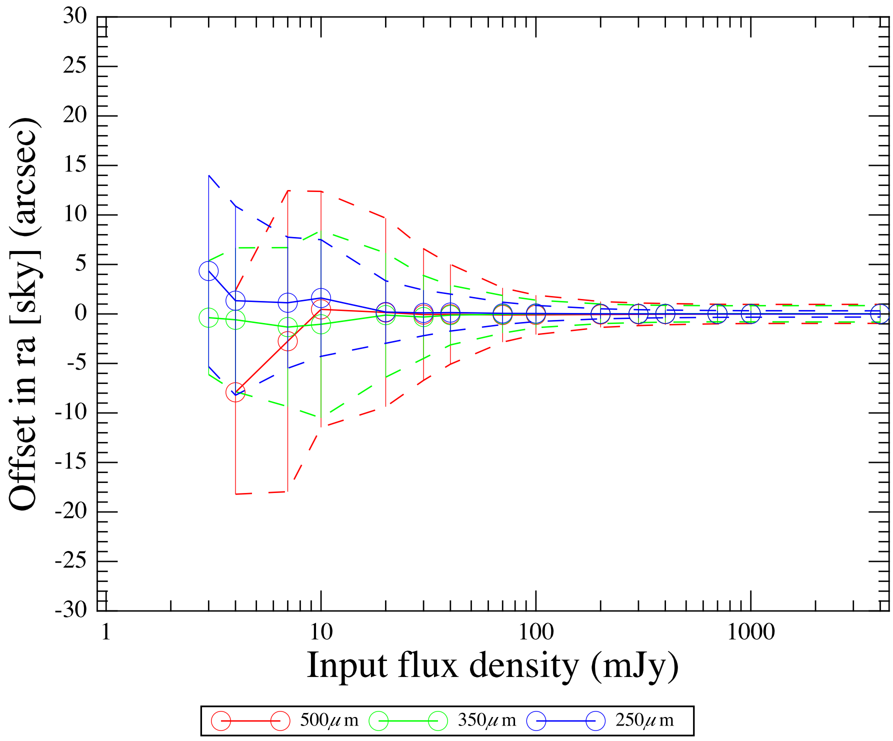

Figure 4: Positional accuracy of right ascension for SUSSEXtractor on the Lockman-North data.

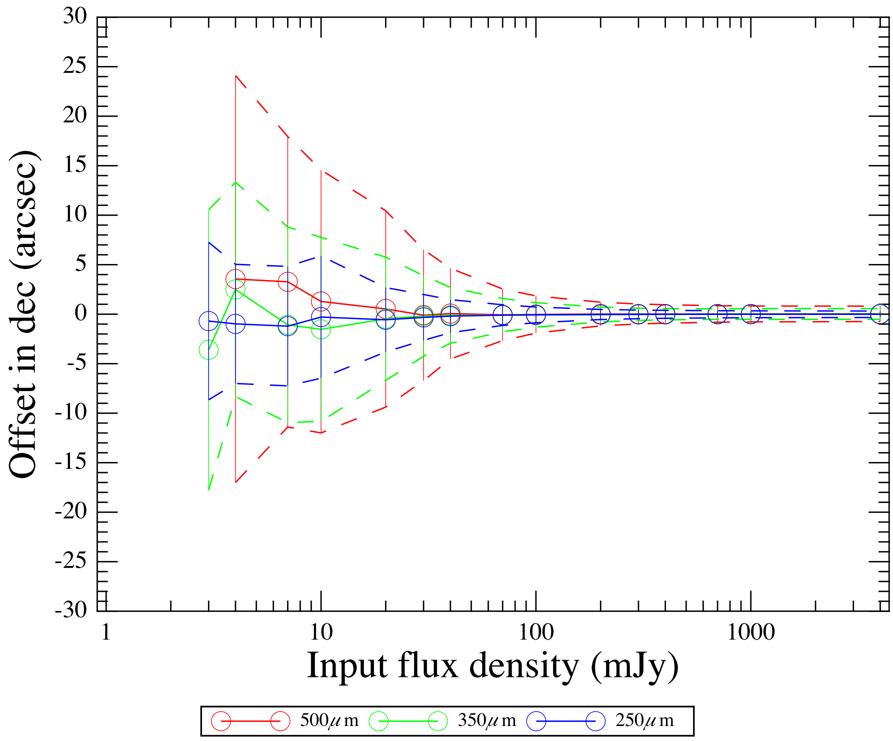

Figure 5: Positional accuracy of declination for SUSSEXtractor on the Lockman-North data.

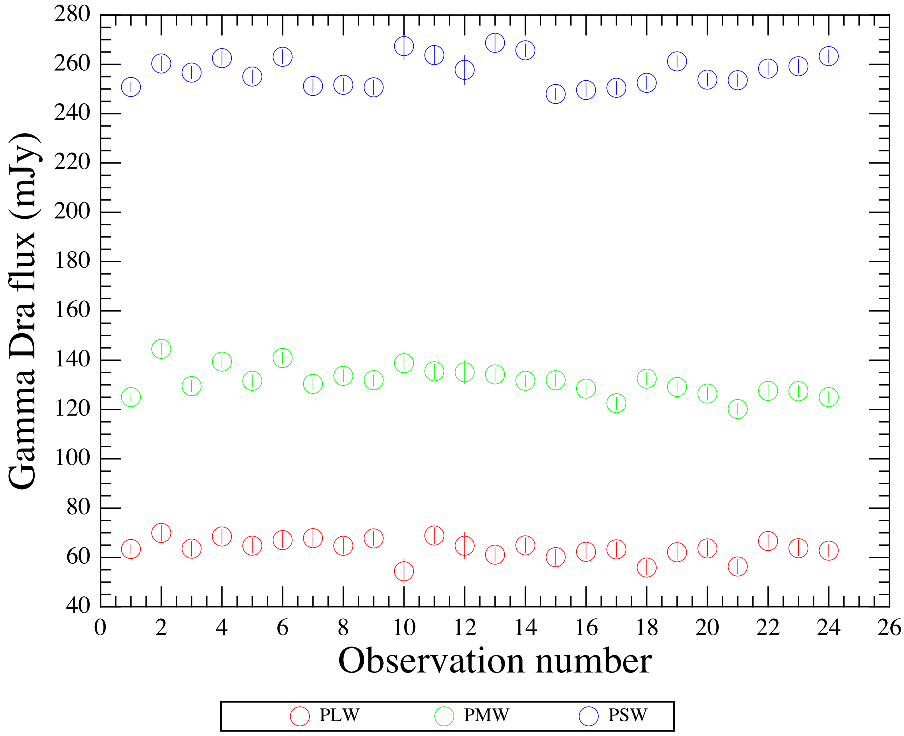

Figure 6: Measured flux of Gamma Draconis using SUSSEXtractor, for the observations listed in Section 1.2.

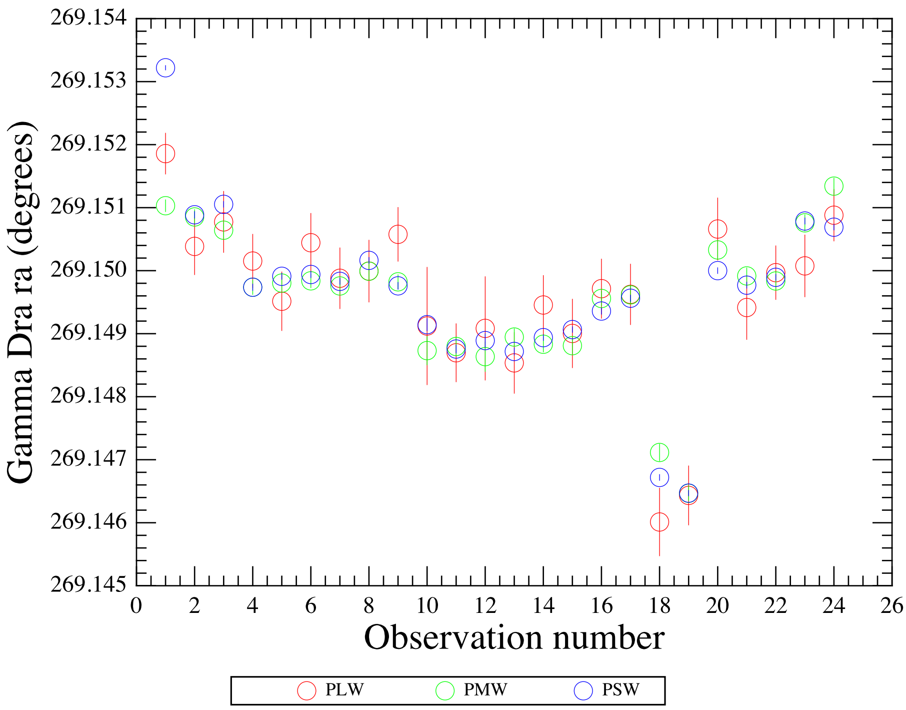

Figure 7: Measured right ascension of Gamma Draconis using SUSSEXtractor, for the observations listed in Section 1.2.

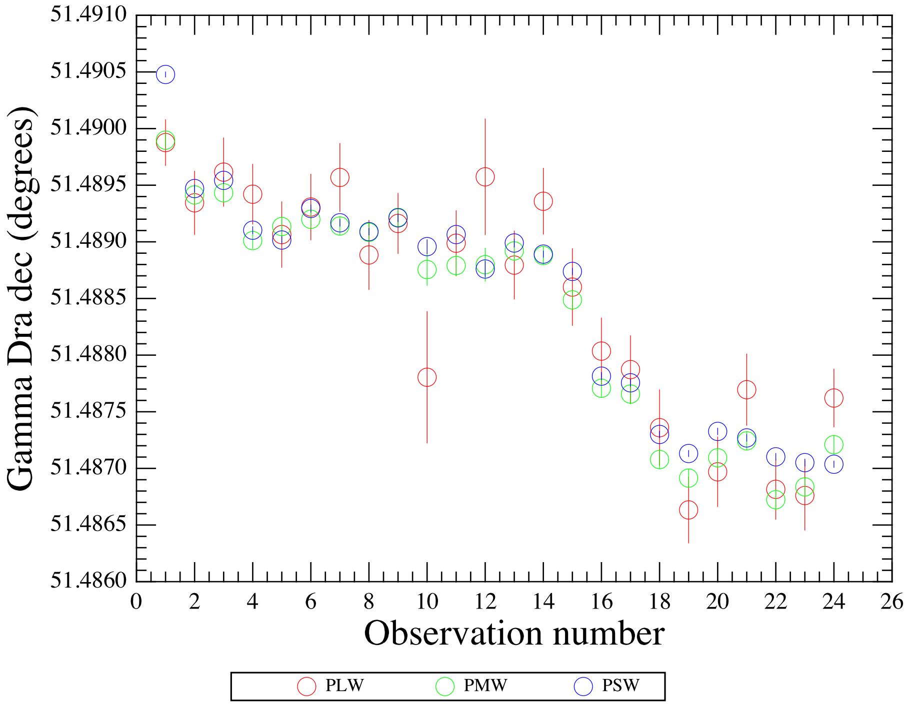

Figure 8: Measured declination of Gamma Draconis using SUSSEXtractor, for the observations listed in Section 1.2.

4 Results for DAOPHOT

4.1 Extragalactic data with DAOPHOT

DAOPHOT was used with its default settings, and in the Lockman-North image it made (1355, 643, 215) detections in (PSW, PMW, PLW). Again, there was no evidence of spurious detections.

Figure 9 shows the completeness, with 50% completeness being achieved at flux densities of (17.8, 22.1, 27.2) mJy for (PSW, PMW, PLW). This is noticeably brighter than for SUSSEXtractor.

Figure 10 shows the flux density accuracy for the same data. DAOPHOT systematically underestimates the flux densities of injected sources, probably because it needs to apply corrections to the fluxes because of the size of the aperture used (the DAOPHOT fluxes are aperture fluxes). Typically the fluxes are underestimated by between 7 and 10%.

Figures 11 and 12 show the positional accuracy in right ascension and declination respectively for the same data. The behaviour is as expected, and very similar to SUSSEXtractor, both qualitatively and quantitatively. (The offsets at very faint fluxes are likely to be due to there being only one or two sources with good matches.)

4.2 Calibration sources with DAOPHOT

The flux of Gamma Draconis was measured using DAOPHOT, with the same parameters as in the previous section. Measured fluxes and positions are shown in Figures 13–15.

Comparison with Figures 6–8 for SUSSEXtractor suggest that most of the variation in measured position is not due to the algorithm, but is rather due to the astrometry of the images themselves. For the measured fluxes, there is much similarity between the two algorithms, but

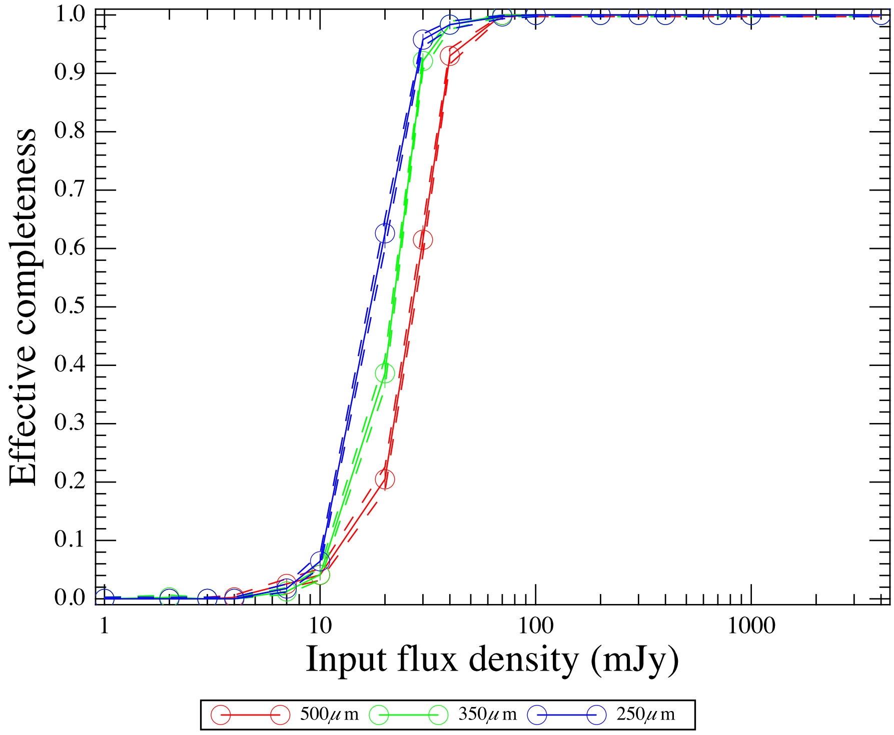

Figure 9: Completeness for DAOPHOT on the Lockman-North data.

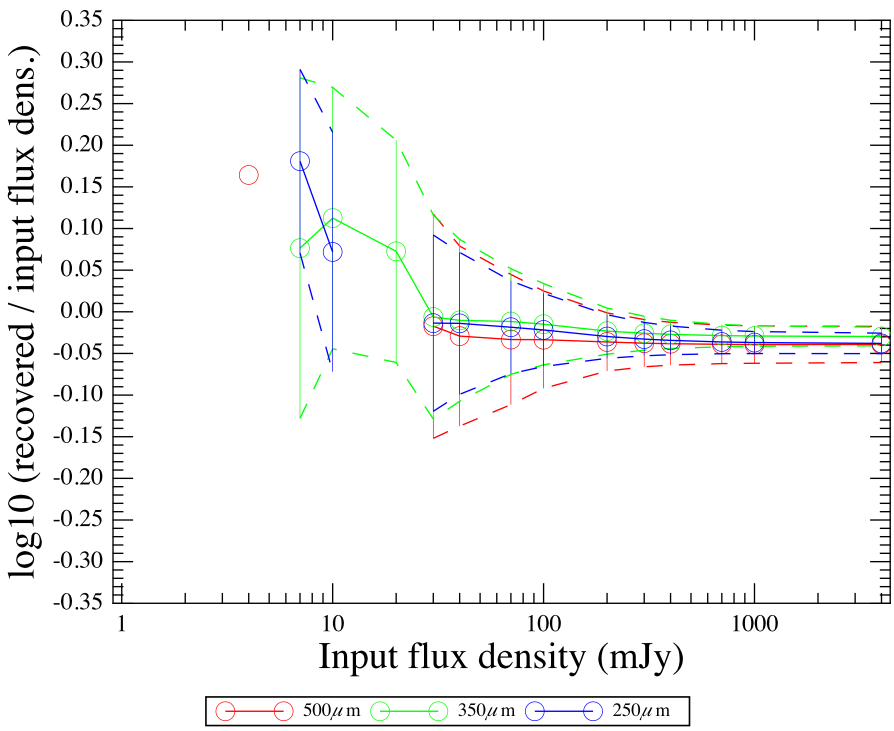

Figure 10: Accuracy of flux densities for SUSSEXtractor on the Lockman-North data.

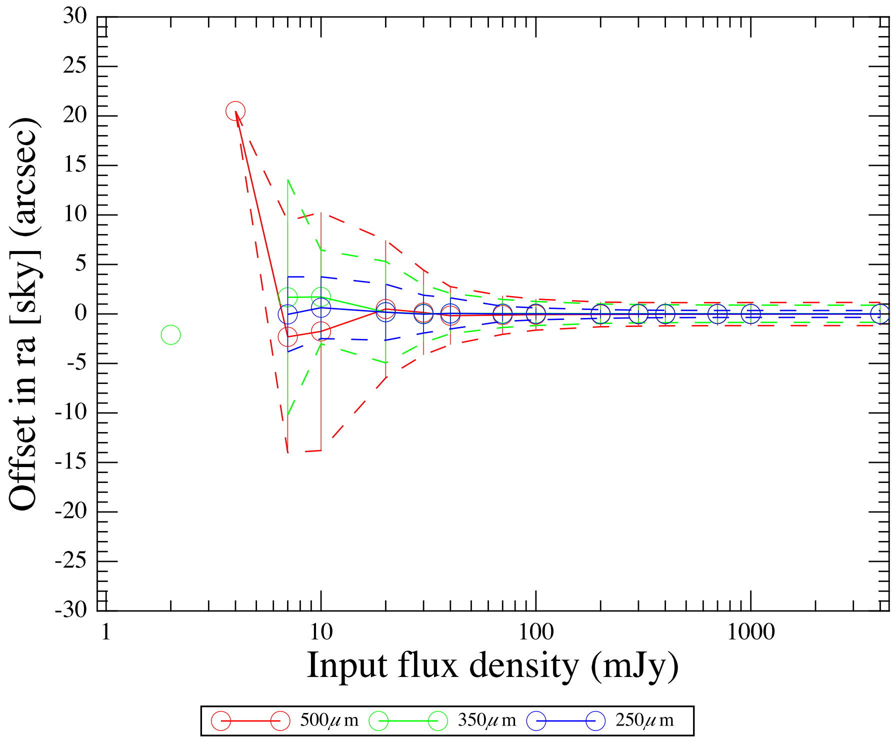

Figure 11: Positional accuracy of right ascension for SUSSEXtractor on the Lockman-North data.

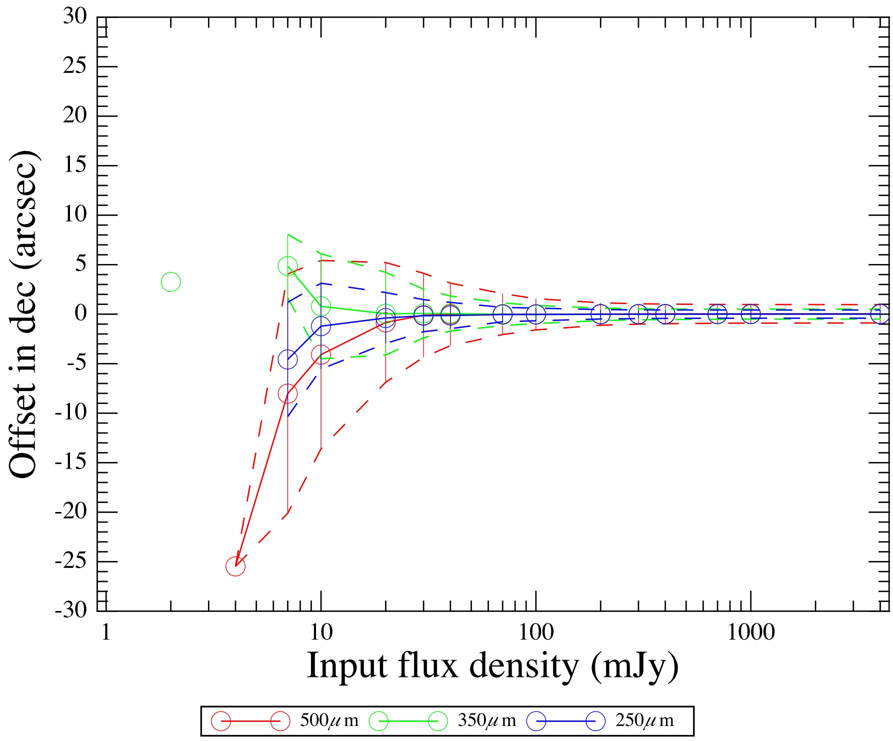

Figure 12: Positional accuracy of declination for SUSSEXtractor on the Lockman-North data.

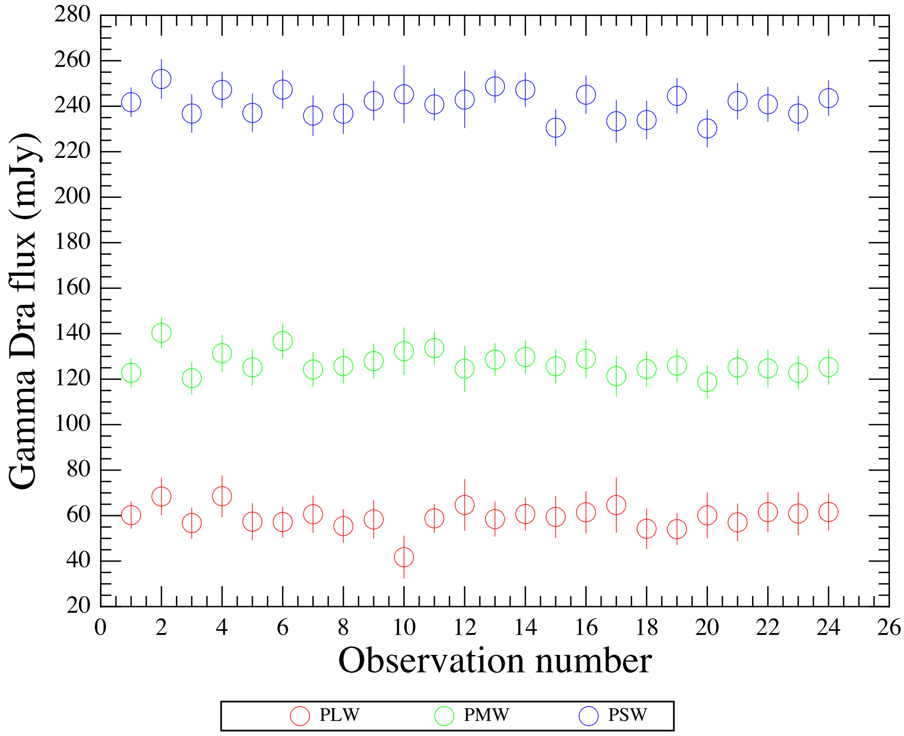

Figure 13: Measured flux of Gamma Draconis using DAOPHOT, for the observations listed in Section 1.2.

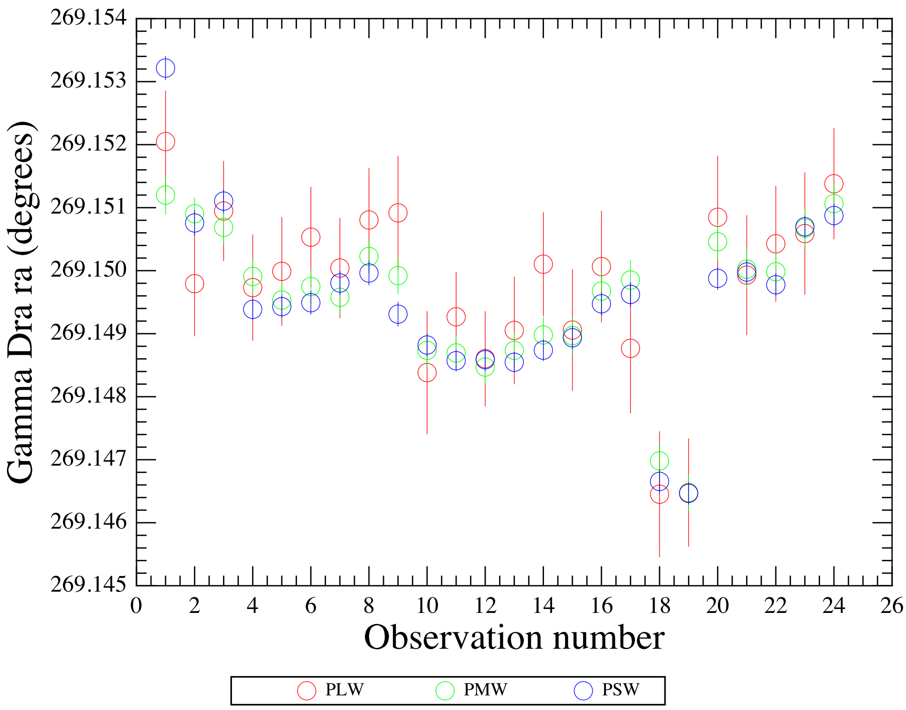

Figure 14: Measured right ascension of Gamma Draconis using DAOPHOT, for the observations listed in Section 1.2.

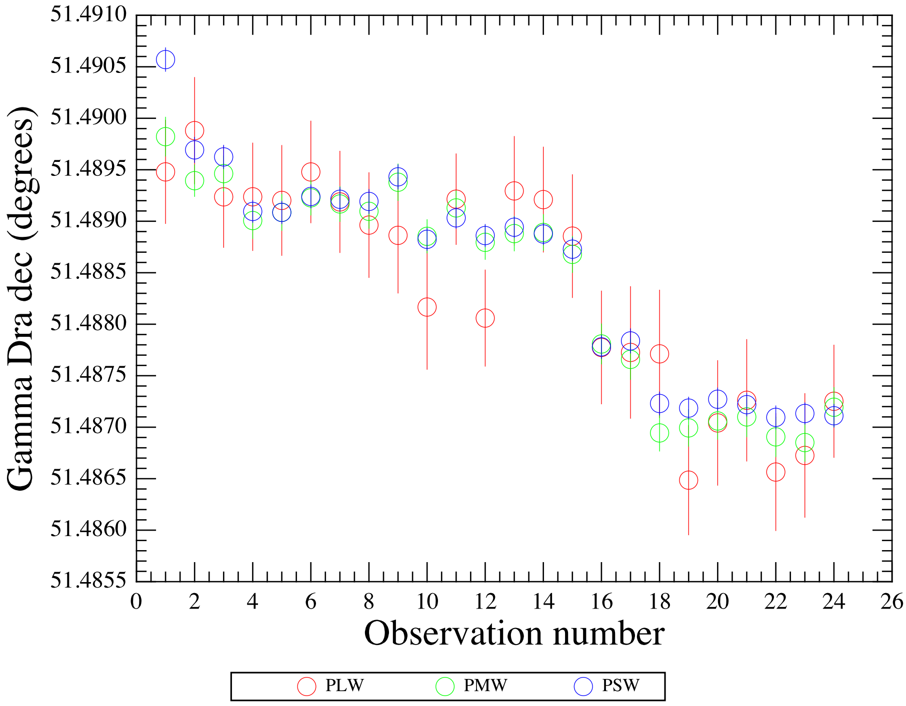

Figure 15: Measured declination of Gamma Draconis using DAOPHOT, for the observations listed in Section 1.2.

there is also some variation depending on the algorithm used. On average, the DAOPHOT fluxes are lower than the SUSSEXtractor fluxes, but not by a large amount.

The median measured flux is (242.0, 125.5, 59.8) mJy for (PSW, PMW, PLW), which is less than the model fluxes of (252, 128, 62) mJy by 2–4%.

5 Conclusions and recommendations

Tests have been performed using SUSSEXtractor and DAOPHOT on flight data from SPIRE, both of an extragalactic field and of a calibration source (Gamma Draconis). The main conclusions are as follows:

1. The algorithms in general do a good job of detecting and measuring sources in crowded fields, with SUSSEXtractor showing a greater ability to detect faint sources (less than 30 mJy).

2. However, both algorithms systematically underestimate the fluxes of the sources, when sources of known profile are injected into the images. For the calibration source (Gamma Draconis), this is not the case, with SUSSEXtractor overestimating the fluxes and DAOPHOT underestimating the fluxes, by 2–4% on average. There could be various reasons for this, such as inconsistencies in the calibration, or an incorrect profile being assumed for the source by the source extraction code.

3. Neither algorithm detects a significant number of spurious sources (this is because both algorithms are local algorithms, and do not introduce large-scale noise effects).

The recommendations of this report (with associated SxRs) are as follows:

1. Checks should be made on SUSSEXtractor to prevent it from systematically underestimating fluxes of artificial sources [HCSS-8346, HCSS-11006, HCSS-11571, HCSS-11572].

2. Aperture corrections should be applied to DAOPHOT fluxes [HCSS-11573].

3. Once the internal consistency of SUSSEXtractor has been established (so that it returns the correct fluxes for artificial sources), tests should be performed to make sure it gives correct fluxes for calibration sources. It is likely that this would depend on the point response function assumed by the source extractor (currently a Gaussian of fixed width) [HCSS-13218].