Bandmerging of Spitzer Detections in the SWIRE Fields

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Abstract

The Spitzer Wide-area InfraRed Extragalactic (SWIRE) Survey has imaged 49 square degrees of high-Galactic-latitude sky in seven infrared bands spanning wavelengths from 3.6 microns to 160 microns, with beam sizes ranging from 2 to 40 arcseconds. Lists of extracted sources from the individual bands are merged using the Spitzer bandmerging software. Positions and their uncertainties are used to identify possible band-to-band matches, then decision theory is applied to make a best match. We present our assessment of bandmerging reliability based on analysis of the random match rate, and we discuss our application of constraints of multi-band detections and proximity to produce reliable catalogs. We examine the crucial role played by positional uncertainties for extractions made with SExtractor and with Spitzer's Astronomical Point-source EXtraction (APEX) software.

The Spitzer/SWIRE Bandmerging Challenge

The SWIRE survey is relatively shallow, with about two minutes of integration time per point in the mid-infrared, and less time at the longest bands. The challenge in making catalogs of galaxies from these data is two-fold. First, the resolution of the sources varies greatly owing to Spitzer's small (85 cm) primary mirror diameter. Second, the sensitivity to galaxies is highest in the shortest two bands and lowest in the longest bands, due to the near absence of background in IRAC Channels 1 & 2 as well as differences in detector technology. Therefore, the detected source density and the resolution vary strongly with wavelength, as shown in Figure 1 and Table 1.

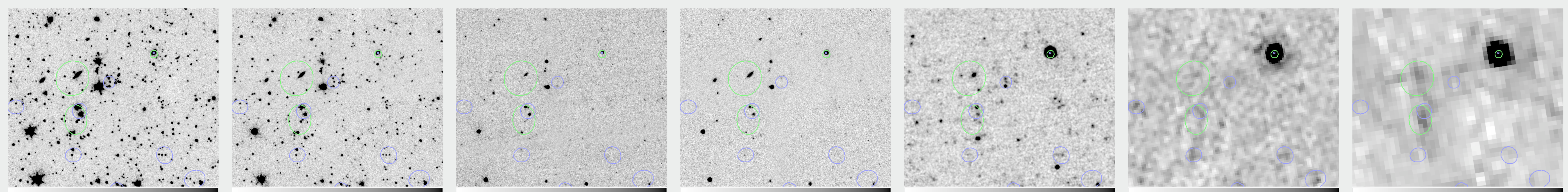


Figure 1. Subset of images in all seven Spitzer bands, increasing in wavelength from IRAC Ch1 3.6um (left) to MIPS 160um (right). The images are each 6.0 by 5.3 arcminutes on a side and are taken from the 2.5deg x 3.0 deg SWIRE Chandra Deep Field South (CDFS) region. Green ellipses denote the 3-sigma centroiding uncertainties for 160um detections with SNR > 3, and blue ellipses are 3-sigma uncertainties for 70um detections with SNR > 3. Some of the detections are spurious--only those matching a well-detected 24um source will be retained in the final catalog.

	IRAC Ch1	IRAC Ch2	IRAC Ch3	IRAC Ch4	MIPS 24	MIPS 70	MIPS 160
Nominal Wavelength (microns)	3.6	4.5	5.8	8.0	24	70	160
Resolution (arcsec)	2	2	2	2	6	17	40
Source density (#/sq arcmin)	14.9	10.85	2.31	1.55	3.97	0.21	0.078
Beams per source	77	100	500	740	32	76	37
Ch1 sources per beam	0.013	0.013	0.013	0.013	0.12	0.94	5.2

Table 1. Characteristics of the seven Spitzer imaging band data in the SWIRE survey that are relevant to bandmerging of sources.

The SWIRE Bandmerging Approach

The 4 IRAC bands + MIPS-24

For the merging of the four IRAC bands and the MIPS-24 band, we have been using the Spitzer bandmerge program. For each merger seed-candidate combination, 20 in this case, a chi-squared statistic is constructed from the distance between the sources and their position uncertainties. When a seed has more than one candidate passing the chi-squared threshold, confusion is indicated. After all 20 combinations have been matched, the best merge is determined by following the steps of simple confusion processing, inconsistent chain breaking, excess linkage rejection, and position refinement (more information is available on the Spitzer website at http://ssc.spitzer.caltech.edu).

Position uncertainties play a crucial role in this process. Our IRAC extractions are made using SExtractor (Bertin & Arnouts 1996), which estimates position errors, but these are significantly underestimated compared to the actual separation of e.g. Ch1-to-Ch2 merges. The SWIRE MIPS extractions, by contrast, were made using the Spitzer APEX PRF-fitting source extractor (Makovoz & Marleau 2005). This extraction makes use of an uncertainty image, and when the uncertainty is properly characterized, the resulting position uncertainties accurately reflect the positional accuracy estimated from astrometric 2MASS sources (Figure 2) .

Since the SExtractor position uncertainties are underestimated for the IRAC bands, a global uncertainty value ranging from 0.2-0.4 arcsec is rss'd into the calculation of the positional chi-squared for these bands. Similarly, as shown in Figure 2, a global value of 0.25 arcsec must be rss'd for MIPS-24 for the brighter sources. Thus the merging between IRAC bands is virtually independent of flux or SNR, but merging of MIPS-24 to IRAC depends on 24um SNR (Figure 3).

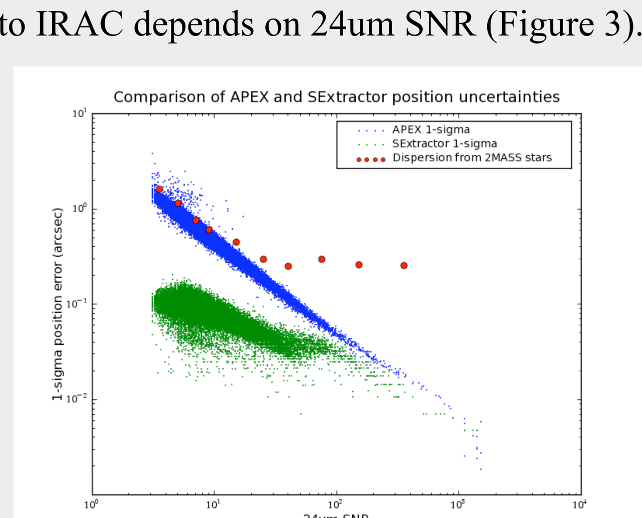
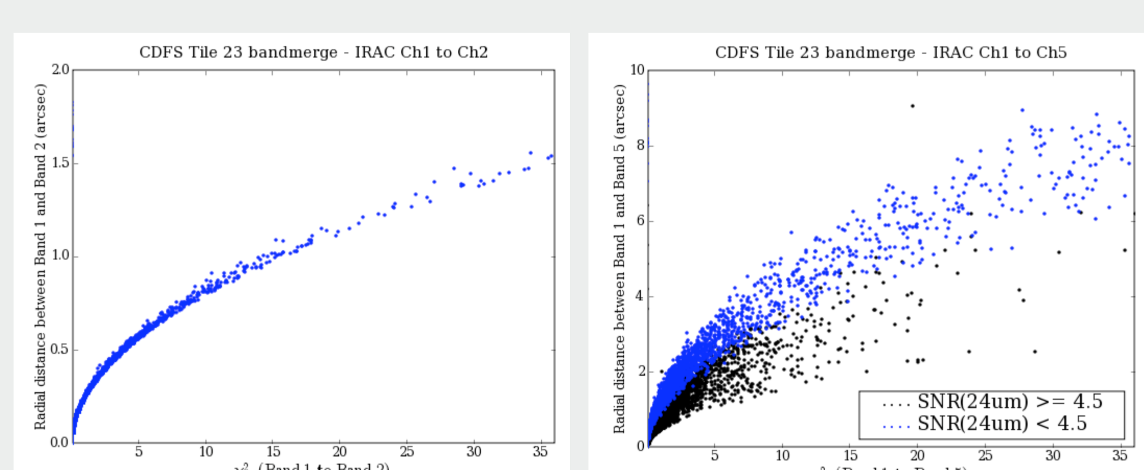


Figure 2. Comparison of positional errors. The dots are 1-sigma position uncertainties from SExtractor (green) and APEX (blue) for extractions from a 24um mosaic, plotted as a function of 24um signal-to-noise ratio. The red balls show the measured dispersion between 2MASS stars and their corresponding 24um extractions. The astrometric accuracy of the 2MASS stars is about 0.1 arcsec. The measured accuracy of the 24um positions is a constant 0.25 arcsec at high SNR, but agrees well with the APEX extraction for SNR values <= 15.

Figure 3. Radial separation of merges as a function of the positional chi-squared. The left plot shows IRAC Ch1 - Ch2 merges, with very little scatter because a single global uncertainty dominates. The right plot shows MIPS-24 to IRAC Ch1 merges, with more scatter for lower SNR sources (blue points) owing to more realistic position uncertainties.



Merging of 70um and 160um sources

Although the Spitzer bandmerge program is capable of merging all seven Spitzer bands, we have taken a different approach. The bandmerge software outputs only a single match even where multiple candidates (confusion) are indicated. SWIRE instead flags primary and secondary matches, so that multiple shorter-wavelength sources may point to the same 70um or 160um source. We match 24um sources to 70um sources within a 6 arcsec radius. Where multiple sources fall within this radius, we select a primary match based on the brighter of the two closest sources. The other matches are flagged as secondary. A similar procedure is followed for 160um except that a 12 arcsec aperture is used. *Only sources matching a 24um source brighter than 0.3 milliJy are considered reliable*. Figure 4 shows the distribution of radial distances between 70um and 160um sources when both are the primary matches to the same 24um source.

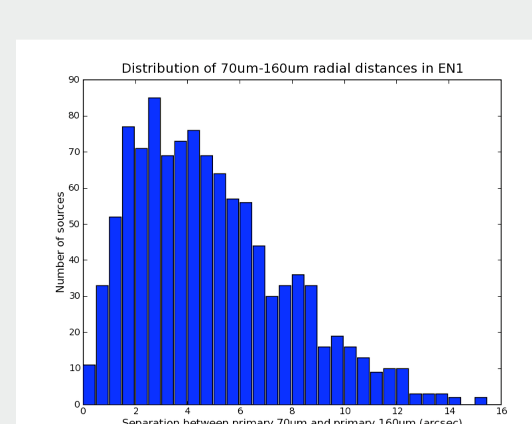
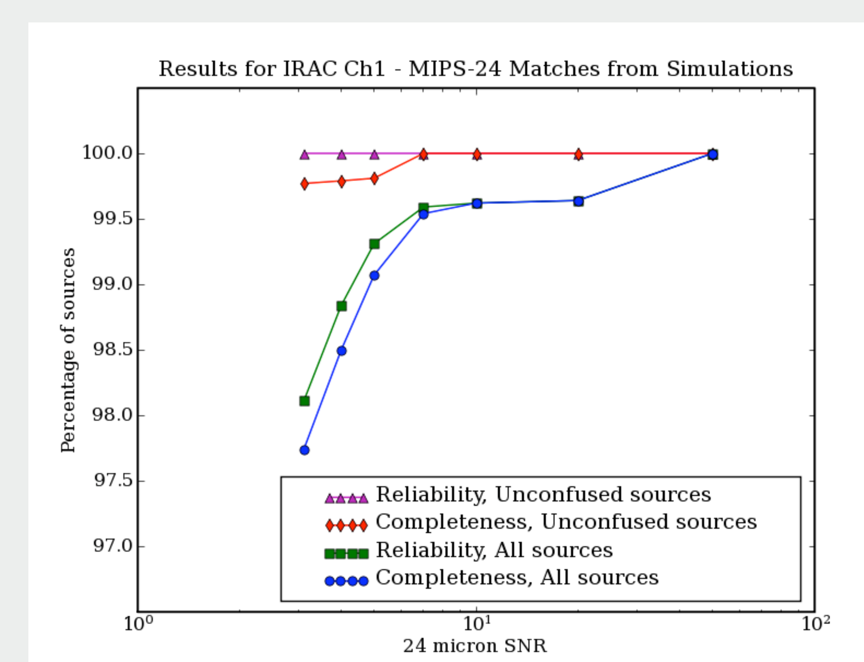


Figure 4. Radial distance between 70um and 160um merged sources. Both sources are a primary match to the same 24um source.

Bandmerging Completeness & Reliability

The reliability of IRAC Ch 1 to MIPS-24 bandmerges has been assessed using two types of Monte Carlo simulations. In the first type, for each MIPS-24 source, we have "cloned" one IRAC Ch 1 source and on Ch 2 source with the positions randomly adjusted according to the position uncertainties. Next, the remaining IRAC Ch 1 and Ch 2 sources are added as "background" with random positions. Then bandmerge is run on the five bands. In the second simulation only random IRAC Ch1 sources are merged with the 24um list. Completeness and reliability are scored by counting correct and incorrect merges. The results for the first case are shown in Figure 5 below.

Figure 5. Reliability and completeness results for simulations in which all 24um sources have a simulated true match in IRAC Channels 1 & 2., Unconfused sources are those having no more than one match candidate that passed the position chi-squared threshold.



The overall reliability depends on the true fraction of MIPS-24 sources that are expected to have a real detection in IRAC Ch1. For the totally random case, about 8% of MIPS-24 sources pick up a false match. If 90% of 24um sources have a true match and 10% do not, then the overall reliability from this simulation at low SNR is 0.9*0.981 + 0.1*0.920 = 0.975 overall, and 0.992 for unconfused sources.

Summary

- The bandmerging of Spitzer sources in the SWIRE survey is complicated by the large beamsizes at long wavelengths and the high source density at the shortest wavelengths.
- The bandmerging process for the shorter wavelengths is based on a positional-chi-squared calculation in which positional uncertainties play a crucial role. The APEX PRF-fitting extractor produces realistic uncertainties for low SNR detections.
- The 70um and 160um bands are merged by matching in a fixed radius with the intermediate 24um band. Where there is more than one potential match, the brighter of the two closest sources is selected. Only those sources matching a 24um source of brightness > 0.3 milliJy are considered reliable.
- Simulations of the merging of the IRAC bands and MIPS-24 indicate a reliability of about 0.975 for all merges and a reliability of 0.992 for unconfused sources.

References

Bertin, E. & Arnout, S. 1996 A&AS, 117, 393.

Makovoz, D. & Marleau, F.R. 2005, PASP, 117, 1113.