Wide-field Infrared Survey Explorer (WISE)

Multiband Source Detection Peer Review Report

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WSDC D-A002

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1 INTRODUCTION

A peer review of the design of the Multiband Source Detection (MDET) module of the WISE Science Data System was conducted by the WISE Science Data Center on December 7, 2007. The MDET module is responsible for detecting sources on WISE image frames and coadded images. A unique feature of MDET is that it detects source on the images from the four WISE bands simultaneously.

MDET functionality, design and algorithms are described in the MDET Subsystem Design Document. (WSDC D-D004).

1.1 Review Panel Members

John Carpenter (Caltech)
Ranga-Ram Chary (IPAC/SSC)
Mehrdad Moshir (JPL)
Leonidas Moustakas (JPL)

1.2 Instructions for Review Panel

The peer review panel was asked to comment on the following specific questions*:*

- Does the design of source detection program address the requirements on the system?
- Are the source detection algorithms suitable and appropriate to carry out the system functions?
- Is the design robust to circumstances that will be encountered with the WISE data?

In addition, comments on other aspects of the design we welcomed.

Written reports were received from Carpenter, Chary, Moshir and Moustakas. These reports are provided below. In addition, miscellaneous comments that were recorded by R. Cutri during the review are also summarized below.

1.3 Applicable Documents

WSDC Functional Requirements Document (WSDC D-R001)
WSDS Functional Design Document (WSDC D-D001)
MDET Subsystem Design Document. (WSDC D-D004)

2 PANEL REPORTS

2.1 John Carpenter

1) In general, the multiband-detection algorithm makes intuitive sense for situations where the PSF is roughly the same size and the sky "looks" the same in each band. And for a large part of the sky I can imagine this will work very well. However, the WISE completeness and reliability requirements are stringent, and therefore I am concerned about the robustness of the algorithm. Specifically:

a) My main concern is how well the algorithm will identify the correct number of sources and assign the correct flux when faced with i) confused regions in 3.3/4.7um, ii) the larger PSF at 23um, and iii) a sky that that looks different at 23um compared to 3.3 and 4.7um. (I realize flux measurement is not part of this subsystem and not subject to this review.)

b) I am also concerned if features in one band (e.g. saturated stars, nebulosity, cosmic rays) will create false sources in another band or cause sources not to be identified in the other bands. Again, this may be more of a concern in confused regions then isolated fields. As I think this through many of these problems may be alleviated in the source measurement stage when chi-squared values are computed.

Our revised algorithm, in which we augment the multiband detection list with single-band detections, addresses this (see item 3.1 of RESPONSES below).

You and Ken are aware of these issues so I am not telling you anything new. The test results to date look promising, and you just need additional tests to verify the robustness. Perhaps tests on the GLIMPSE and MIPSGAL data will be useful in this regard.

2) I had concerns coming into the review about moving objects such as asteroids and high proper motion stars. Any concerns regarding asteroids are irrelevant since they are not factored into the requirements.

But I am concerned about the specific case where the proper motion is high enough such that the coadded image is "blurred" and more than one source is identified. High proper motions stars are few in number and the completeness/reliability requirements will not be compromised by these alone. Nonetheless, it would just be a shame to get these sources "wrong". I do not have a specific recommendation other than perhaps you can have special treatment for these sources as you do for the known asteroids.

If such objects are bright enough to be detected on the single scan exposures, the single-frameset stage of source extraction (in the scan/frame pipeline) will provide single-epoch extractions appropriate to moving sources. These can be "linked" after the fact. However, a object too faint to be detected in the individual frames, and that is moving fast enough to trail

on the coadded image (yet still be detectable given the trailing losses) may not be possible to detect unambiguously. This is a fundamental limitation of the WISE mission design.

That is pretty much I all I have. I am impressed with the work Ken has done to date and this is certainly is a very promising start.

2.2 Ranga-Ram Chary

I thought since it was an initial effort, quite a bit of testing and validation is required.

I strongly encourage testing on SWIRE data blurred to the appropriate beamsize and GLIMPSE data where part of the confusion noise comes from spatially extended sources.

I also suggest actually Airy function like PSFs for the 24 micron data to identify if the MDET picks up spurious sources around the Airy rings (which is what SExtractor does unless you provide a proper convolution kernel). Note that I am not emphasizing Airy functions for the other 3 channels because my understanding was you couldnt see them at the current spatial resolution.

At all wavelengths we use our best estimate of the actual PSF. Any spurious detections of Airy-ring structure will be filtered in the final product generation stage (i.e. catalog selection) using chi squared values derived in the photometry step in WPHOT.

One key point which I thought hadn't been taken into account is that its difficult to identify and centroid on undersampled PSFs. Are we sure that the current MDET doesn't identify some of the 3.6 micron sources (especially the faint ones which may not have flux spread over multiple pixels) as cosmic rays ?

MDET does not attempt to distinguish real sources from cosmic rays – that is the job of the final catalog selection using chi squared values and frame detection statistics derived in WPHOT.

I don't think detecting on the stack of all 4 images is worthwhile. I think addition of the longer wavelength data increases confusion in the shorter wavelength channels because of the larger FWHM at 24 microns. I also think that since typical LIRGs and ULIRGs are likely to have S24>>S3.6 microns, the poisson noise from the source at longer wavelengths might be a significant factor. Simulations need to be made to see if this 4 band stack is worthwhile, with realistic extragalactic source count models (e.g. Papovich et al. 2004 for 24 microns, Fazio et al. 2004 for 3.6 and 4.5 microns). I think the source density at 3.6 and 4.5 microns is going to be larger than that at 12 or 24 microns. Therefore, based on past experience, I recommend source detection on the stack of 3.6 and 4.5 microns and a stack of 12 and 24 microns followed by a merging of source lists to do photometry/point source fitting.

Please see item 3.1 in RESPONSES below.

The confusion noise treatment is too idealized. Confusion is not Gaussian i.e. 5*1_sigma_confusion is not 5*sigma_confusion. Confusion can arise from the contribution of individual sources which are below the detection threshold of the survey or from extended sources e.g ISM in the Galactic plane. Again, simulations need to be done to show that the code works in both regimes.

Please see item 3.3 in RESPONSES below.

My impression from the simulations presented was that the source detection is not working very well at faint flux densities. The images (e.g. slide 15) seem to show that its ~30-50% complete. When comparisons are made as in slide 16, the comparison should be made with the number of input sources above the 5sigma and 20sigma detection limit rather than just between single band and multiband.

The color stretch of those images is a little deceptive – they used a log stretch with a cutoff at the 1-sigma level. So the majority of the undetected sources are probably noise bumps. We will indeed check future simulated detections against truth tables to confirm that we are detecting at a sufficiently low threshold to meet the missions completeness requirements (they were not available for the simulations I showed, however).

It is a bit unclear if the identification of extended or point sources will be done in the detection step of the process or the source fitting step of the pipeline. The confusion arose from the statement about "profile-fitting photometry routine" without having the images convolved to the same resolution. Without convolution, all sources will have different profiles at different wavelengths depending on their spatial extent and the PSF. It seems to me that spatial extension should be best decided at the highest resolution channel (i.e. 3.6 microns) and then the appropriate isophote within which the flux is measured decided based on the PSF. That is, a source maybe extended at 3.6 microns but compact at 24 microns. The way I have done it with GOODS is to do point source fitting at 24 microns but use apertures at 3.6 microns. How do you plan to tackle this ? Furthermore, since there are likely to be low-z sources extended in all 4 wavelengths - in that case you would either have to convolve all to the same resolution and use the same isophote or carefully choose the isophote at each wavelength after looking at the neighborhood of individual sources to avoid contamination from other sources.

Identification of extended sources will be deferred to the subsequent photometry step (WPHOT module) by examining the quality of the fit to a point-source profile. The baseline requirements of WISE do not include the generation of an extended source catalog. However, it is a goal to include flagging that denotes sources that are not well-fit by a single point spread function.

We have used Singular Value Decomposition to do simultaneous source fitting for multiple point sources. But this is for WPHOT, not the MDET.

2.3 Mehrdad Moshir

I am happy to see an attempt is made to enhance source detection technology using multiband data. The team who is working on the WISE processing is top notch and experienced in many aspects of the problem and I am confident they will deliver a high quality product.

This particular approach has come up in my previous projects and the reason we did not in the past pursue it was that the existing methods do a good enough job and the benefits may not be high enough to counteract the risks.

Regarding the benefits, the analysis study that Ken showed us did not yet convince me that the gain was of such a magnitude that could counteract potential unknowns. The unknowns are the behavior of the instrument compared to going in assumptions. We have all seen surprises crop up once on orbit. I suggest that a serious analysis using Spitzer data plus simulations take place to demonstrate the method's enhanced benefits.

We agree, and our planned tests (and tests already performed) make heavy use of Spitzer data (IRAC + MIPS 24 µm).

Regarding uncertainty distributions, as I said on Friday it is OK to use a "Gaussian equivalent" sigma, but at least half of the sky will show a non-Gaussian behavior, with the result that the "Gaussian equivalent" width would be smaller than otherwise. This will lead to a detection threshold that is lower than intended, with the result that more detections will enter your candidate pool; the characterization step will have to deal that problem.

In the detection step with MDET, the goal is completeness, so we are prepared to tolerate substantial numbers of false detections. The weeding-out of false detections is deferred to the final catalog selection step using information derived in source characterization in the WPHOT module.

One other suggestion I have is that before spending a lot of time and resources to answer some of these questions, previous work could be looked at. For the Spitzer source extractor (APEX) David Makovoz did a lot of analysis of the optimal filtering for non-gaussian noise and his work should be available on the Spitzer disks (Russ Laher may be able to point to them).

We will certainly take a look at David's analysis work.

I also recommend that assumptions on the behavior of data should be checked against instrument lab data.

Agreed. As more information becomes available from ground testing we will incorporate it, particularly with regard to PSF behavior.

Final point is that the software should be very robust to on-orbit realities, for example a kill switch that allows you to proceed at a reduced performance (but at least as good as a single band source extractor) if the data have artifacts that are outside of the assumption space.

We will be augmenting the multiband source list with single-band detections to avoid such problems (please see item 3.1 of RESPONSES)

2.4 Leonidas Moustakas

* It is good that the algorithms are being developed as early as they are, and subjected to some peer review. As there are naturally many unresolved issues that have not yet been explored or quantified, it would make good sense to plan on (at least) one more peer review, say in a year's time.

* The multiband-detection algorithm is interested and certainly worth exploring more. I wasn't completely convinced that this is the best approach for WISE, though. It would certainly be the optimum approach for bands that have very similar resolution and depth, and for objects that do not have extreme colors across the bands. I believe that is the basis of the Szalay et al (1999, AJ, 117, 68) paper. It is worth following up where that 10-year old algorithm has gone, and what other types of data it has been applied to.

We have been in touch with A. Connelly (one of Szalay's co-authors) regarding this. Besides those authors' work with HST data, it has been used for the VIRMOS deep imaging near IR survey (Iovino et al. astro-ph/0507668). Apparently, no significant problems were encountered. It should also be noted that Connely reported that they intend to use multiband detection as part of LSST data processing.

* To reinforce this last point, over the bands at 3.3, 4.7, 12 and 23um, I believe I could be more easily convinced that combining the three first bands may arguably be fairly robust for isolated-object detections. The robustness of the association of each object with signal in the last channel may be quite hard, especially based on the anecdotal experience that Chary was telling us about. Perhaps a fairly algorithmic compromise may be possible, wherein the detections are done in the first three bands, a simple one-channel detection on the last one, and then an association is made through a simplified DAOPHOT-style (or for resolved objects, a "TFIT" type procedure http://stsdas.stsci.edu/astrolib/tfit_users_guide.html).

Please see item 3.1 of RESPONSES below.

* I appreciate that there hasn't been much time yet to study large sets of 'emulated' data based on real 2MASS+Spitzer data, and that very little simulated data have been built yet. I recommend putting a great deal of effort in building a range of simulated datasets, for experimenting with the real advantages and problems of the current adopted algorithm (and simple variants, such as the one above). It will be important to build simulated datasets that have objects with reasonable

colors that correspond to each of the classes of objects that WISE will be probing: LIRGs/ULIRGs and high-redshift QSOs as well as cool stars. Especially in relatively crowded fields, the potential problem of confusing the association of objects by wavelength might become very obvious.

I'm looking forward to seeing where this goes, and if it is possible to get an update a few months down the line, I would be grateful.

2.5 Misccellaneous Comments Recorded at Review

Peter Eisenhardt – How will performance of MDET be tested?

Our test plan involves both simulated WISE data (incorporating our best knowledge of instrumental parameters) and real (Spitzer IRAC + MIPS 24 μm) data, with heavy emphasis on the latter. Since the primary goal for detection is completeness, our tests with the simulated data will involve careful comparisons with the truth tables of data generation. The use of Spitzer data will ensure that the detectioin performance in the vicinity of various types of astrophysical objects (particularly extended sources such as galaxies) is well understood.

Peter Eisnenhardt – Detection efficiency of single-band sources is important. Primary science target of WISE is brown dwarfs which will likely by band 2-only detections.

Please see item 3.2 of RESPONSES below.

Mehrdad Moshir – What will be effect of multiband detection on sources that have truly different photocenters at different wavelengths?

Since the detection process is optimized for point sources, different photocenters will be treated as separate sources during this step.

Mehrdad Moshir – How is noise in subtracted background captured?

The background noise estimate will be based on the histogram of residuals between the observed (coadded) image and the estimated slowly-varying sky background using the same window size chosen for the median filtering of the background. The noise sigma will be obtained from the difference between a pair of histogram quantiles, as discussed in item 3.3 of RESPONSES below.

Ned Wright – Might be able to come up with a better approximation to the confusion noise combination that adding in quadrature.

Please see item 3.3 of RESPONSES below.

3 RESPONSES

3.1 Cross-band confusion effects:

Issue: Because of the larger PSF at 23 μm and/or the presence of extended sources at 23 μm, nearby sources at the shorter wavelengths may get lost in the wings when the images are stacked.

Recommendations:
(a) Make partial stacks of images rather than stacking all four --- either in pairs (3.3+4.7 and 12+23) or three at a time (3.3+4.7+12) and bandmerge the results.
(b) Validate with real data, particularly Spitzer (GLIMPSE, MIPSGAL, SWIRE).

Response: This is an issue of which we have been aware from the outset. Our initial expectation was that any sources missed in the detection step due to cross-band confusion effects would be restored during the active deblending procedure in the subsequent profile-fitting photometry step. Specifically, a missing source would give a high value of reduced chi squared for the profile fit, and that would prompt the deblending procedure to add an additional component. As a result of recent testing with Spitzer data, we now realize that there are situations in which active deblending would fail to restore the missing source. For example, if the confusing source is extended (most commonly a galaxy), the high chi squared may be dominated more by the residuals associated with the galaxy rather than to the omission of a neighboring point source. In such a case, the algorithm would try to fit a set of point sources to the galaxy profile rather than try to restore the missing point-source neighbor. Based on these considerations we have now implemented an alternative scheme in which the detection list from the stack of 4 bands is augmented with single-band detections where necessary. This preserves the optimal detection sensitivity associated with using all data at once, while not sacrificing any completeness.

3.2 Detection efficiency of single-band sources:

Issue: In the stacking process, do "dropout bands" (i.e., those bands in which a source is not detected) add noise?

Response: An image in a dropout band would contribute only minimally to the detection signal since the expectation value of blank sky is only one sigma, and this would have only a small effect on the resultant when combined in quadrature with a signal of several sigmas. In any event, the effect can only be to increase the resultant, which means that a source which is above the detection threshold in a single band will still be above the threshold in the combined image. The optimality of the multiband

detection procedure does not involve any assumptions about the source spectrum and is not biased against sources with extreme spectra, i.e. those which have little or no flux in one or more bands.

We will include the efficiency of detection for single-band sources as part of the MDET unit testing plan.

3.3 Adjusting the detection threshold in confused regions:

Issue: Is it valid to add a term in quadrature to the measurement noise to account for confusion? If so, can confusion noise be modeled as Gaussian to a sufficient approximation, and should one base the detection threshold on the 1-sigma width of the distribution or the 5-sigma width?

Response: The goal here is not to measure confusion noise -- it is simply to respond to confusion by systematically raising the detection threshold so as to reduce the number of spurious detections in problematic fields. That having been said, the justification for our procedure is as follows: Quadrature addition is appropriate because covariances of independent random processes (specifically, measurement noise and confusion noise) are additive, regardless of the forms of the distributions (provided, of course, that the first two moments exist). The tricky part is to characterize the confusion noise by a variance value which maintains the detection characteristics in terms of signal to noise. Our approach is to regard confusion noise as the superposition of a large number of unresolvable blended sources in the telescope beam, in which case the central limit theorem implies that the distribution of beam fluxes will approximate a Gaussian. Superposed on this Gaussian will be a tail comprised of less-numerous resolved and partially-resolved sources. Since this tail will include sources of interest, we base our detection threshold on the main body of the distribution rather than the tail, and have accordingly opted to use the distance between the 16% and 84% quantiles of the sky brightness histogram (approximately the +/- 1-sigma points of an equivalent Gaussian) as a measure of confusion noise. A similar procedure was used successfully to set the detection threshold for confused regions in 2MASS.