# Source Detection

# Multiband DETector (MDET)

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# Overview



## Purpose of MDET:

Generate a list of candidate source positions and relative strengths for use in subsequent photometry (WPHOT)

## Overall requirements:

- Highly complete detection of sources for all pipeline steps
- No effort to eliminate artifacts (artifacts are flagged later)

# Driving Requirements



| | |
|---|---|
| L4WSDC-002: | The WSDC shall produce a Source Catalog derived from the images used to generate the WISE digital Image Atlas |
| L4WSDC-080 | The final WISE Source Catalog shall have greater than 99.9% reliability for sources detected in at least one band with SNR>20, where the noise includes flux errors due to zodiacal foreground emission, instrumental effects, source photon statistics, and neighboring sources. This requirement does not apply to sources that are superimposed on an identified artifact. |
| L4WSDC-009 | The final WISE Source Catalog shall be at least 95% complete for sources detected with SNR>20 in at least one band. This requirement does not apply to sources that are superimposed on an identified artifact. |
| L4WSDC-043 | The WSDS Pipeline processing shall detect sources down to a threshold of at least five times the image noise from the calibrated image frames, and the combined Atlas Images. |
| L4WSDC-044 | The WSDS Pipeline processing shall merge source detections in the four WISE bands into a single source catalog entry. |
| L4WSDC-049 | The WSDS Pipeline shall be robust to data missing from one or more bands. |

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# WSDS Scan/Frame Pipeline

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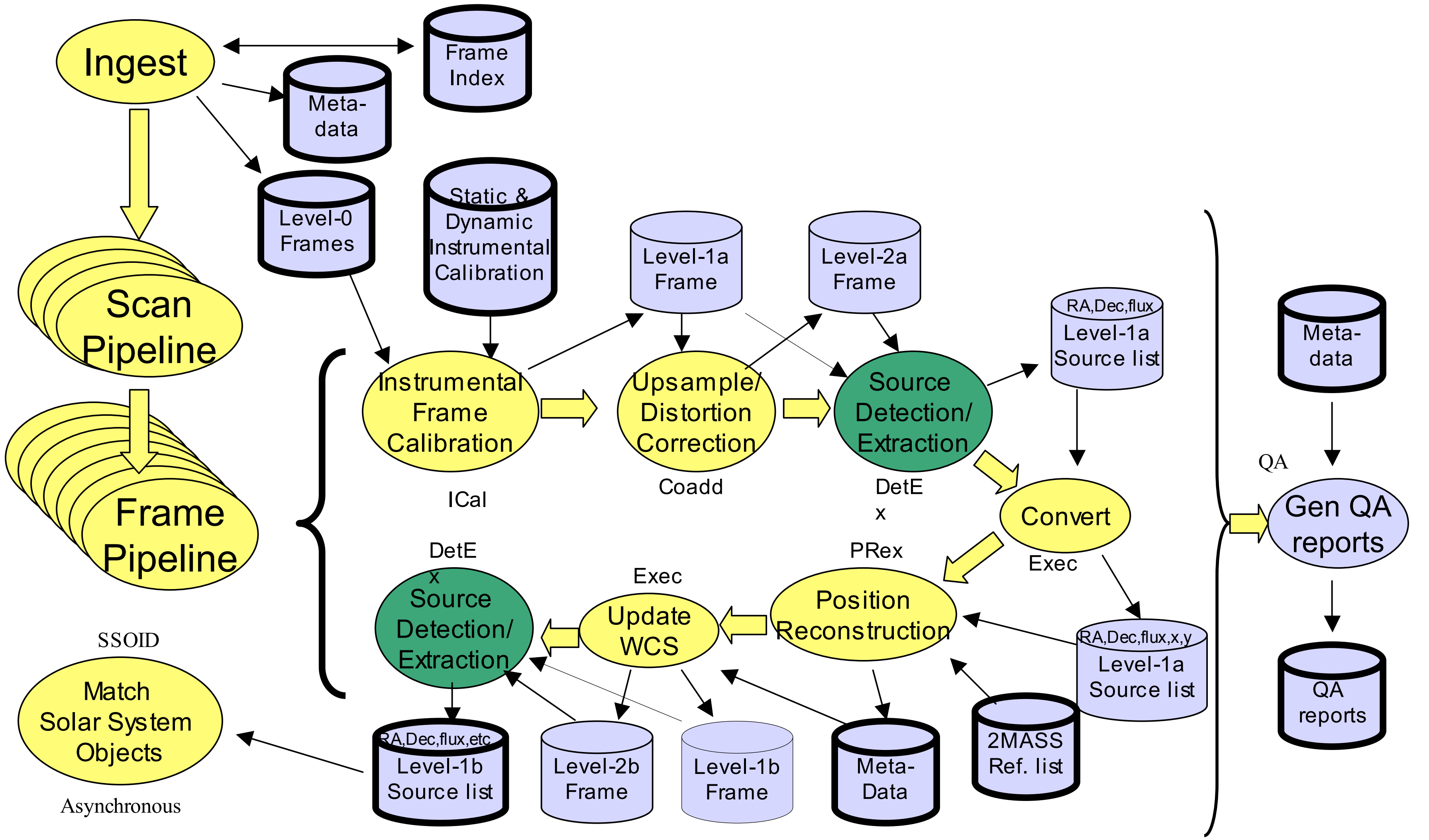
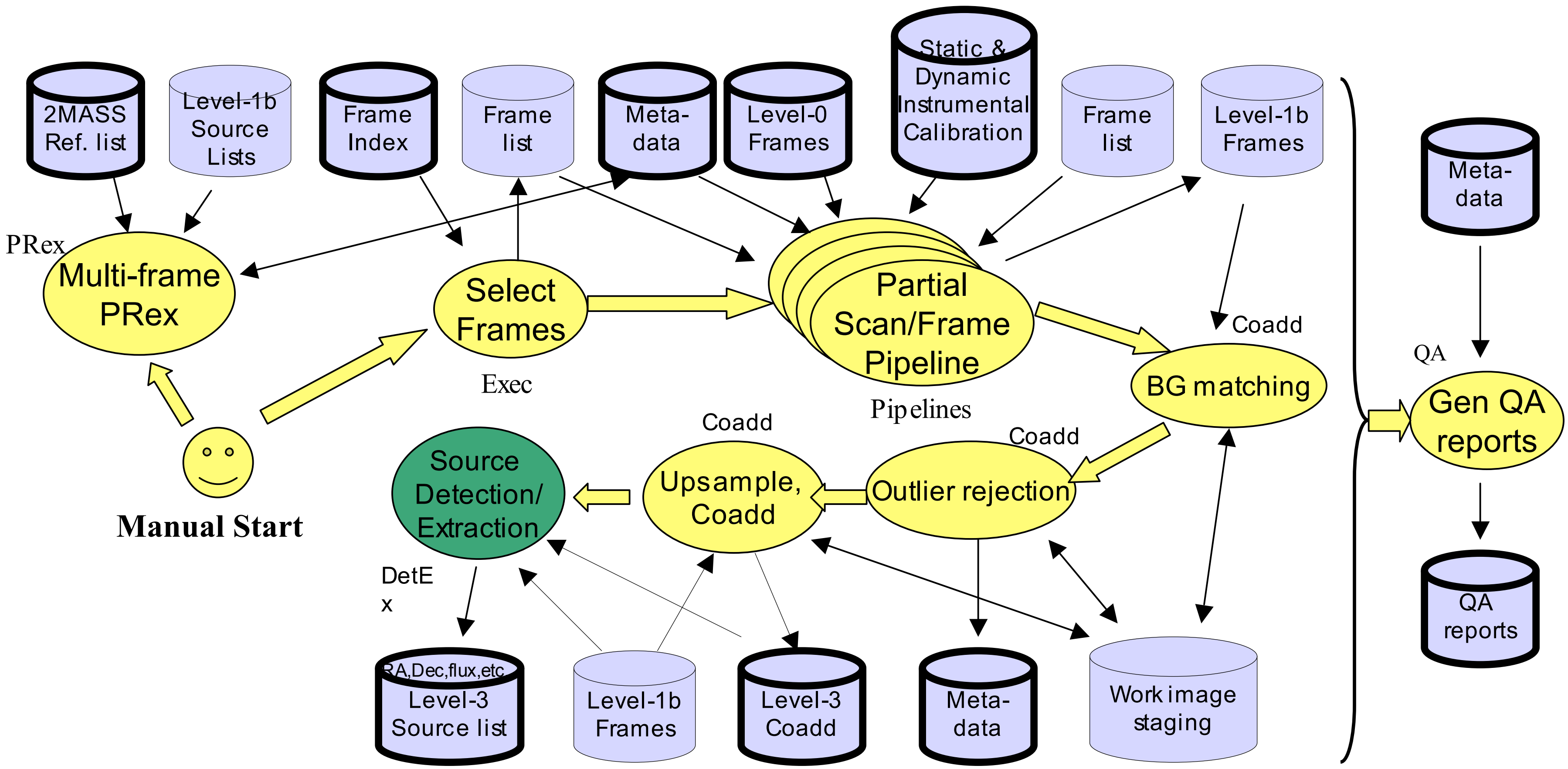



KAM

# WSDS Multiframe Pipeline

MDET



# Multiband Detection



- Detect at all bands simultaneously.
- Advantages (applicable to detection *and* characterization):

1. Increased sensitivity to weak sources due to the fact that detection is based on the stack of images at all bands
2. No separate bandmerging step is required, thus avoiding the ambiguities which can occur when trying to associate sources in different bands in the presence of confusion
3. The higher resolution data at the shorter wavelengths can guide the extraction at the longer wavelengths where the resolution is poorer

# Theoretical basis of multiband detector



## Assumptions:

1. Isolated (non-blended) point source
2. Gaussian measurement noise
3. Background has been subtracted *a priori*
4. No prior information regarding spectral shape

## Principles of mathematical derivation:

1. For each location, **s**, on the sky, compare the hypotheses:
   (A) **s** lies on blank sky
   (B) **s** represents the location of a point source whose fluxes at the various wavelengths are given by the most probable values (with non-negativity constraint on flux representing prior information in Bayesian context)
2. Calculate the relative probability of hypothesis (B) with respect to hypothesis (A).
3. Find the location at which the relative probability is maximized, and evaluate the statistical significance of the presence of a point source at that location.

# Theoretical basis (Continued)



## Resulting procedure:

- Construct a *detection image* in units of sigma; the most likely locations of point sources correspond to local maxima in this image.

$$\phi(\mathbf{s}) = \left( \sum_{\lambda} \frac{1\left( \sum_i (\rho_{\lambda i}/\sigma^2_{\lambda i}) H_\lambda(\mathbf{r}_{\lambda i} - \mathbf{s}) \right)^2}{\sum_i (1/\sigma^2_{\lambda i}) H_\lambda(\mathbf{r}_{\lambda i} - \mathbf{s})^2} \right)^{\frac{1}{2}}$$

- The detection image itself is produced by combining *in quadrature* the matched filter images (normalized by the local sigma) from the individual bands.
- Each term in the above summation over l can be calculated using the imaging output (coadded images and uncertainties) generated by the WSDS Image Coadder (AWAIC) without having to redo the summations over focal-plane pixels. It includes the effect of focal-plane distortion implicit in the mapping (*i*, l ) $\rightarrow$ **s**

# Relationship to previous work



Szalay et al. (1999):

- “Chi squared” method
- Involves quadrature sum of observed (or matched filtered) images at multiple bands
- Detection threshold based on comparison of brightness histogram with theoretical chi squared distribution

Principal difference between MDET and Szalay et al. procedure:

- In MDET, matched filter images are thresholded at zero before adding in quadrature

  -- Corresponds to imposing prior information of non-negativity via Bayes’ rule

  -- Results in sqrt(2) increase in sensitivity

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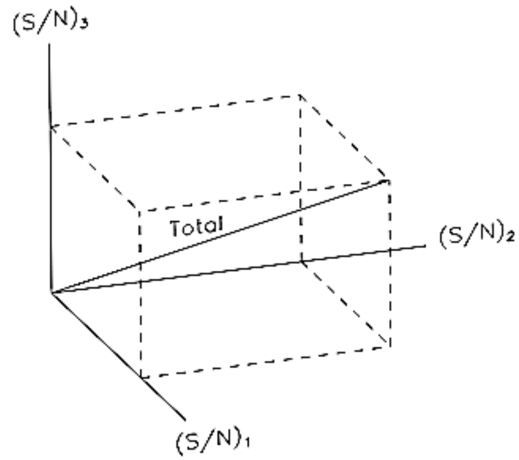
# Implications of quadrature summing of images

MDET

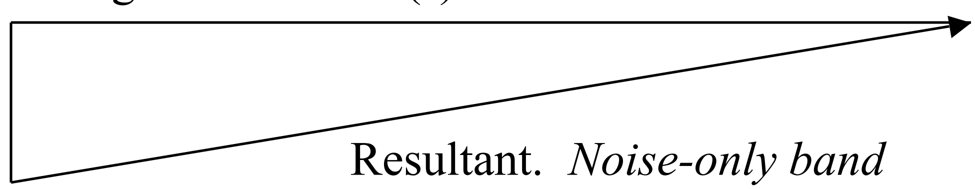
## Geometric interpretation:




## Effect of single-band sources and "dropout" bands:

*S*σ signal from band(s) in which source is detected

1σ signal from noise-only band



Resultant. *Noise-only band has relatively small effect on its length.*

# Algorithmic steps



Inputs:

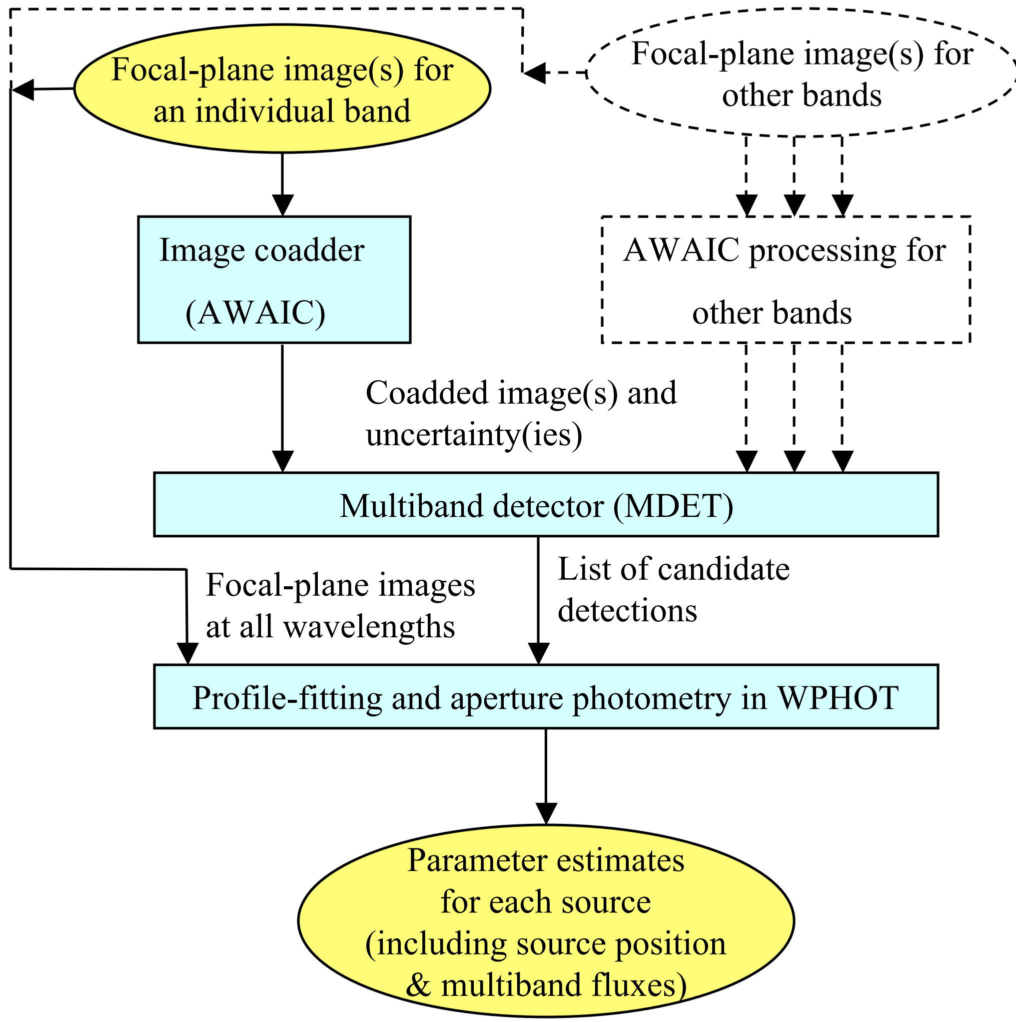
1. Coadded images and uncertainties at all bands.
2. Window sizes for estimation of slowly-varying background (median filtering) and standard deviation of background (via brightness histogram).
3. Detection threshold in sigmas.

Procedure:

1. Subtract slowly-varying sky background from coadded image at each band.
2. Adjust detection threshold in response to confusion by adding an extra term in quadrature to each coadd uncertainty image
   - -- derived from brightness histograms
   - -- effectively raises the flux density threshold in confused regions
3. Calculate matched filter at each wavelength in units of S/N by dividing subtracted coadd image by its uncertainty; threshold at zero (i.e., impose non-negativity constraint).
4. Combined matched filter images in quadrature.
5. List the positions and S/N values of all distinct local maxima which exceed the specified detection threshold.

# Data Flow



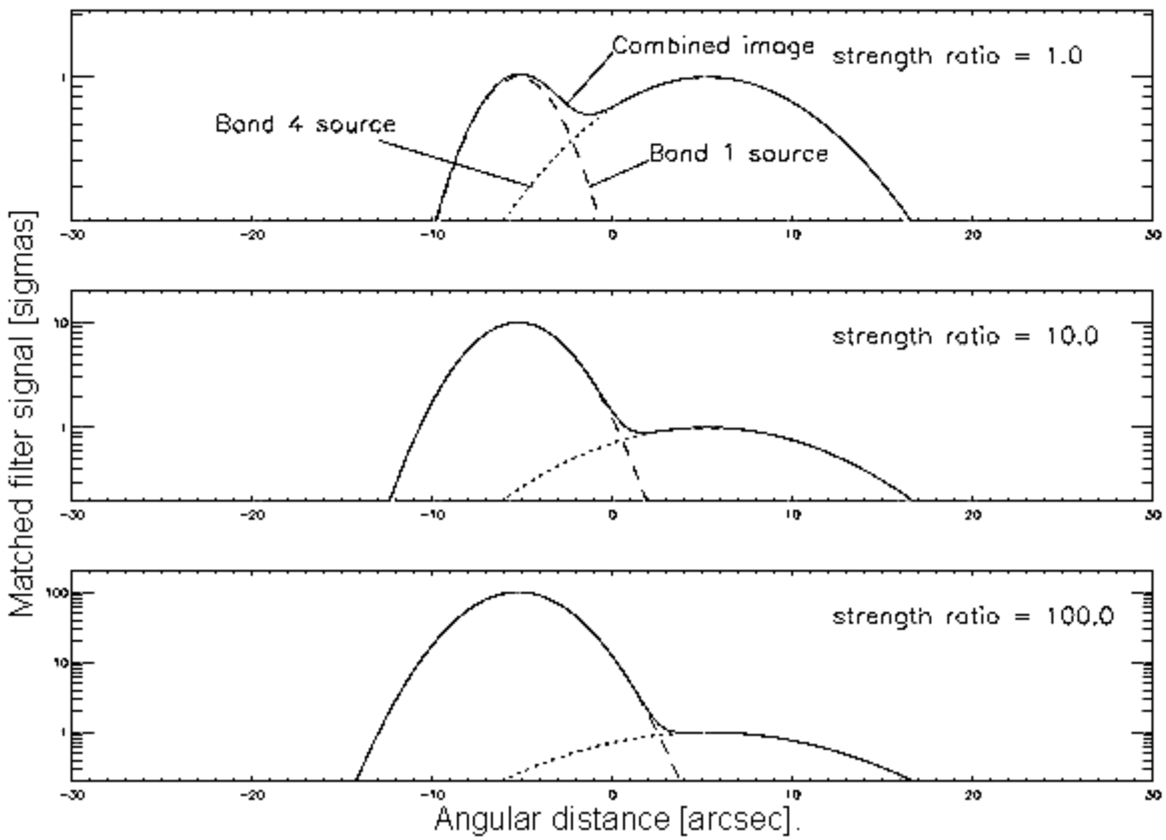

Focal-plane image(s) for an individual band
Focal-plane image(s) for other bands
Image coadder (AWAIC)
AWAIC processing for other bands
Coadded image(s) and uncertainty(ies)
Multiband detector (MDET)
Focal-plane images at all wavelengths
List of candidate detections
Profile-fitting and aperture photometry in WPHOT
Parameter estimates for each source (including source position & multiband fluxes)

# Effect of blended sources



- Blended sources violate the assumption of isolated source.
- Band-to-band effects: A source in one band may be lost in the wings of a close companion source in another band.

Example: Two single-band sources (Bands 1 and 4, respectively) separated by 10.5 arcsec:



# Effect of blended sources (Continued)



Options:

1. Single-band detection + bandmerge (DISADVANTAGES: lose the extra sensitivity gained by stacking images, and spurious detections due to bandmerge ambiguities).
2. Merge the results of multiband detection *and* single-band detection (DISADVANTAGE: spurious detections due to bandmerge ambiguities).
3. Multiband detection, and recover any missing close companions in the parameter estimation step in WPHOT.

Adopted procedure: Option #3

- Will be discussed in WPHOT presentation.

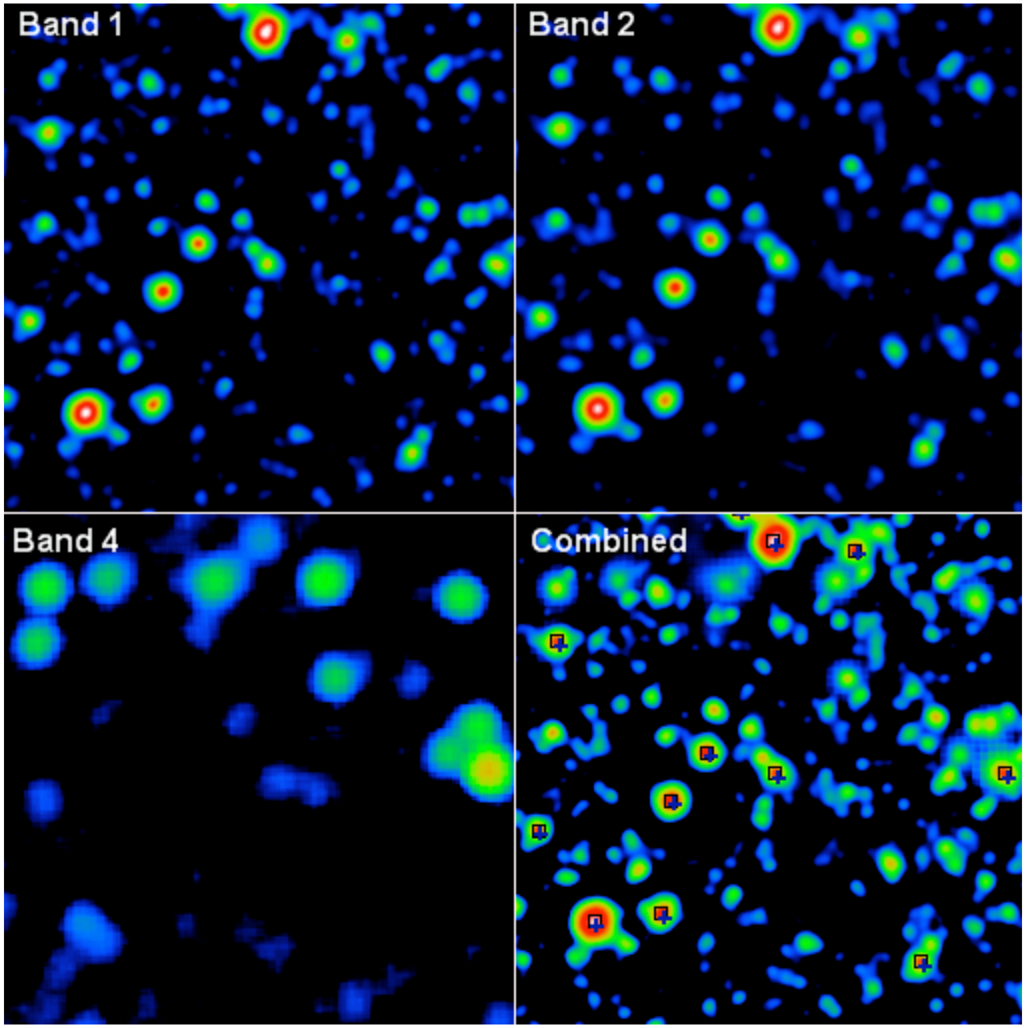
# Tests with synthetic data



- Simulation of Galactic Center region based on 2MASS data (N. Wright)
- 4 focal-plane images 47 x 47 arcmin, one at each band
- Gaussian-shaped PSFs, with FWHMs corresponding to WISE
- Realistic additive noise

# Galactic Center simulation






Field of view of simulation:
47 x 47 arcmin

Subfield shown here:
5.9 x 5.9 arcmin

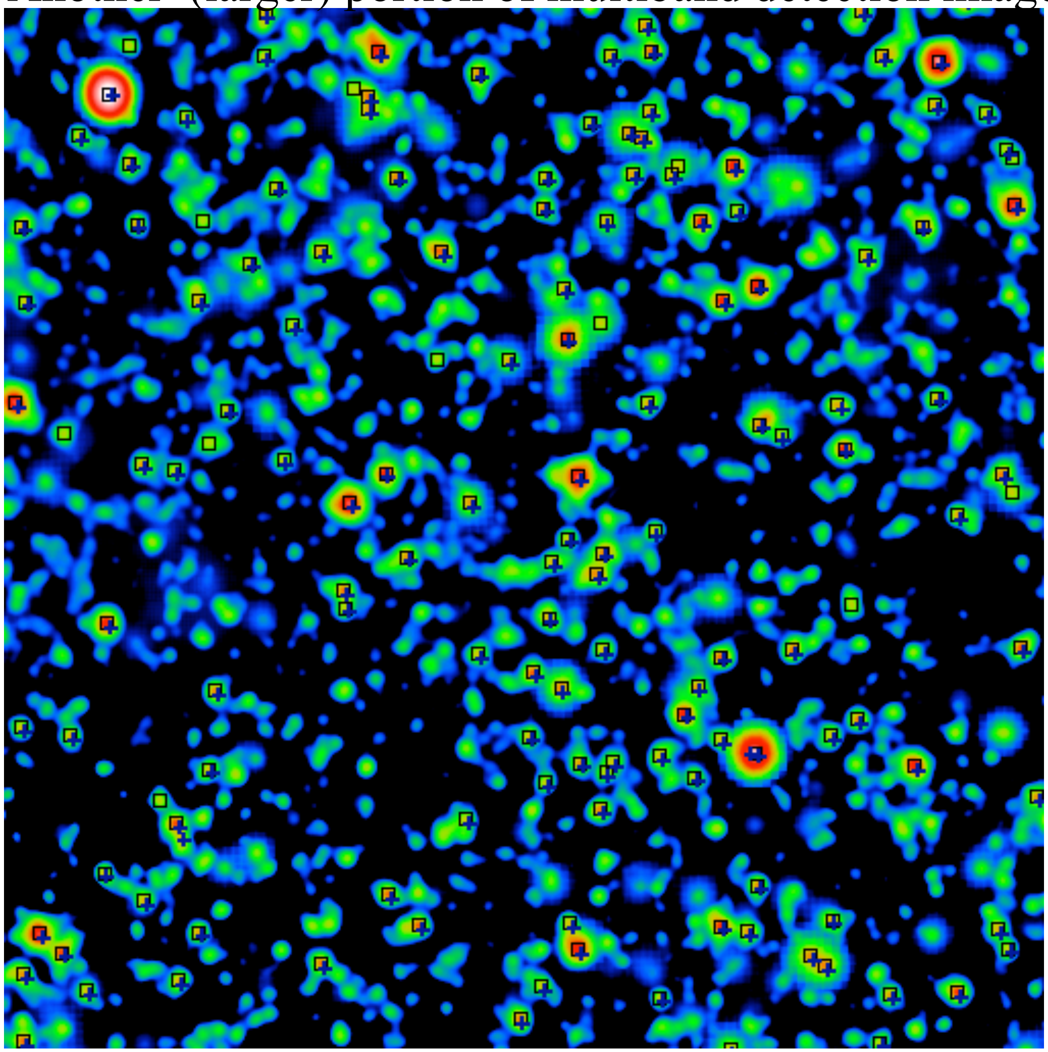
Superposed on "Combined" image (at left) are the locations of 5s detections:

- black squares: multiband detections
- blue crosses: bandmerged single-band detections

# Galactic Center simulation (continued)



Another (larger) portion of multiband detection image (11.7 x 11.7 arcmin):



- Detection threshold = 3s
- In this color stretch, most of the lower-level features are noise bumps

# Galactic Center simulation (continued)



## Summary of results:

| Band: | Number of candidate detections: threshold = 5s | threshold = 3s |
|---|---|---|
| 1 | 972 | 2080 |
| 2 | 254 | 533 |
| 3 | 35 | 74 |
| 4 | 11 | 28 |
| Result of bandmerging single-band detections: | 978 | 2093 |
| Result of multiband detection: | 1107 | 2315 |
| # multiband candidates not in merged list: | 138 | 243 |
| # merged candidates not in multiband list: | 9 | 21 |
| # blended sources missed by multiband detector: | 5 | 12 |
| # spurious bandmerged detections: | 4 | 9 |

# Tests with real data (2MASS + Spitzer IRAC)



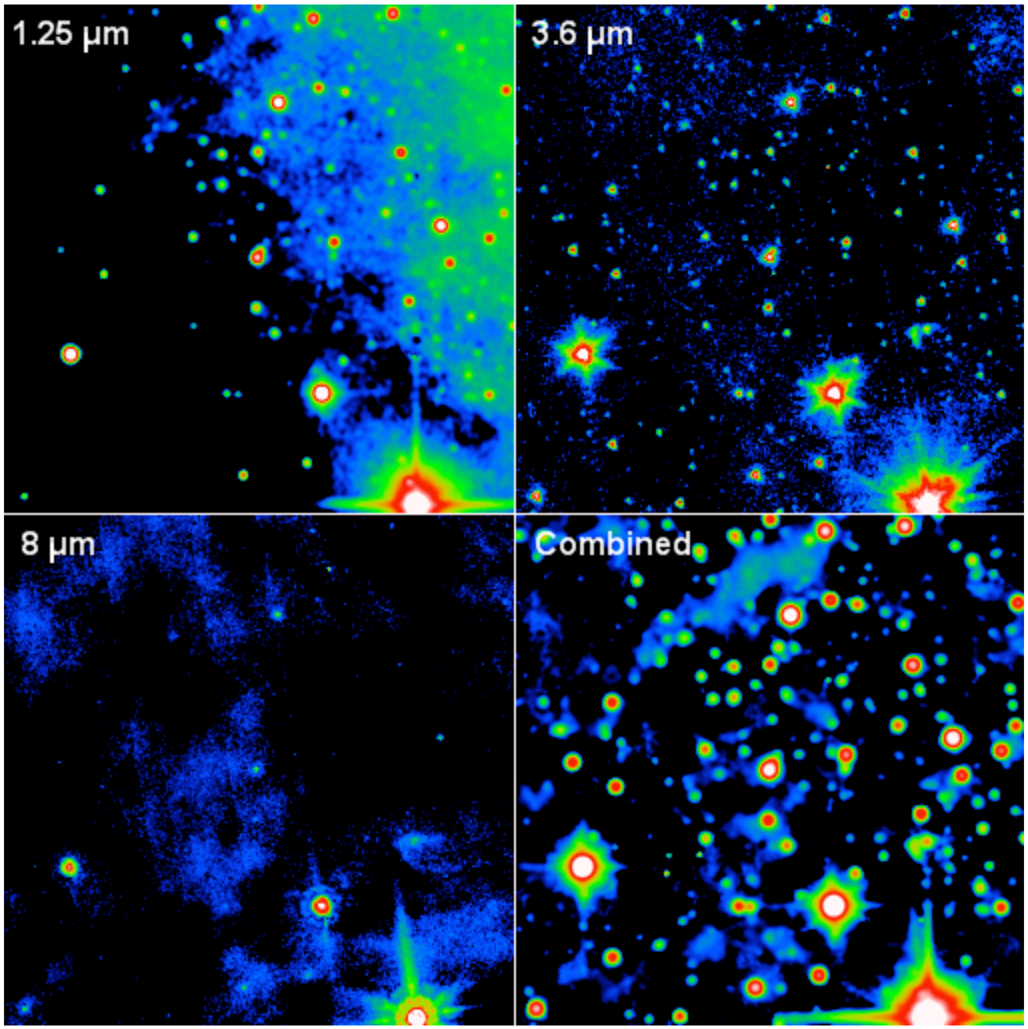
- Analysis of 2MASS Deep Fields under NASA ADP grant *"Optimal Source Extraction from Long-Integration Stacked Images of Calibration Fields Observed in 2MASS"*

  PI: K. A. Marsh (IPAC) Co-I: T. Velusamy (JPL)

  Collaborators: R. Cutri, T. Jarrett (IPAC)
- For fields where Spitzer IRAC data available, do multiband source extraction at 7 bands simultaneously
- Source detection based on same design as the proposed MDET module

# Example: r Oph core region






Observed (coadded) images in 3 of 7 bands, and the multiband detection ("Combined") image.

Field of view:
4.3 x 4.3 arcmin

# ρ Oph source counts

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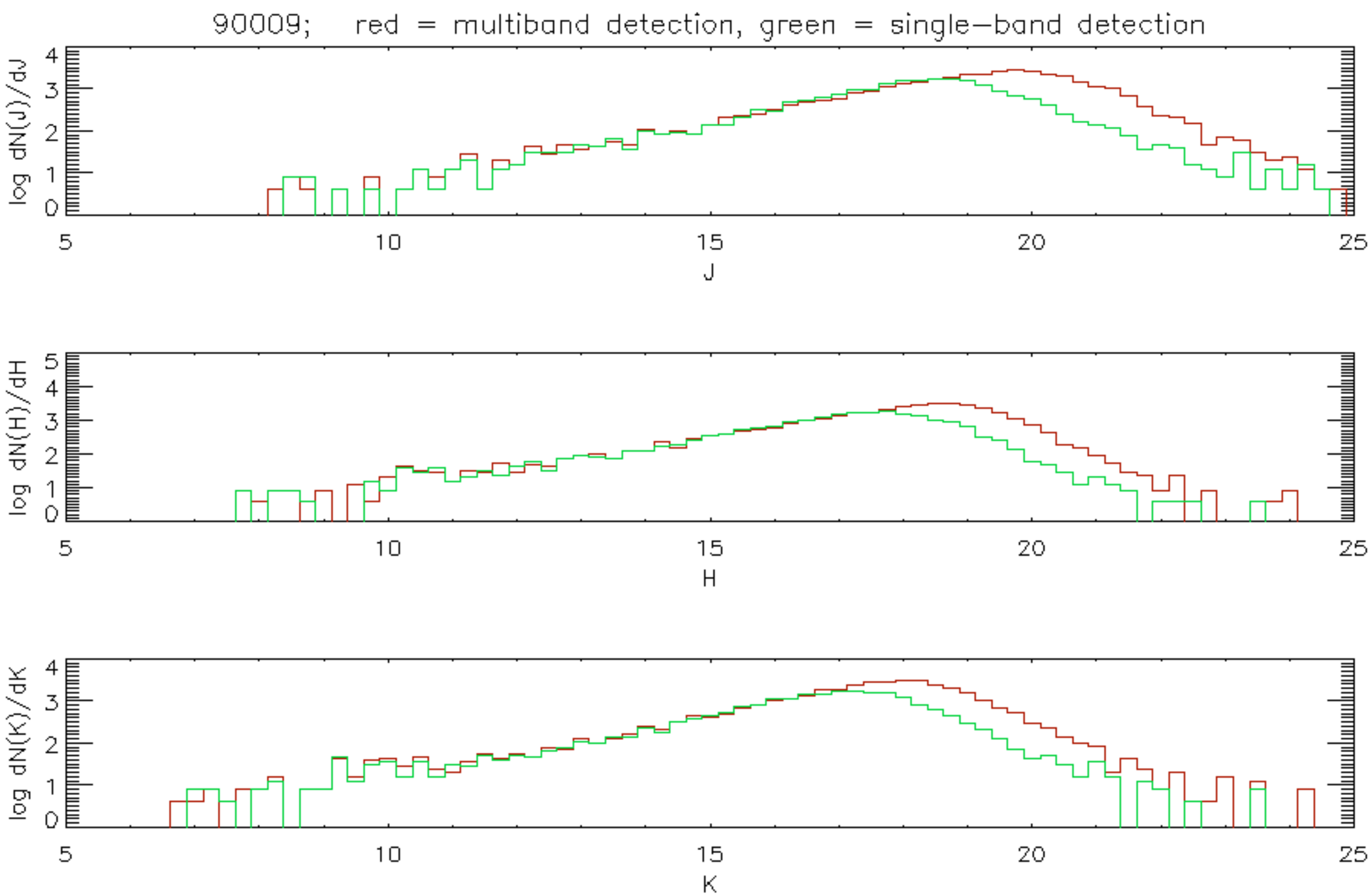

# Peer Review Summary



## Main issue of concern:

- Weak sources in bands 1-3 will be lost in the wings of strong 23 μm sources when images are stacked
- Suggest combining  smaller subset of bands (combine 1-3 and do single-band detection on band 4, or else combine 1,2 and 3,4 separately)

## Response:

- This behavior is fully expected  a small fraction of the time in crowded fields.
- We are doing simulations using IRAC+MIPS to better quantify the effect
- The "missing sources" will be restored during active deblending in WPHOT (WISE PHOTometry module).

# Development Schedule



| Task | Product | Vers. | Deliv. Date |
|---|---|---|---|
| Develop IDL prototype. | IDL prototype | v0 | 2/27/08 |
| Translate code into FORTRAN for integration into pipeline. | FORTRAN module | v1 | 5/28/08 |
| Test with simulated WISE data + real data (e.g. Spitzer IRAC+MIPS)<br>--- debug code<br>--- optimize parameters | Revised code + parameter set | v1.5 | 8/27/08 |
| Fine tuning of parameters/code | Optimized module | v2 | 2/28/09 |
| Ops. readiness testing | Pre-launch params. | v3 | 8/4/09 |
| Tune-up wrt on-orbit performance | Fine-tuned params. | v3.5 | 12/30/09 |
| Final processing | Final code/params. | V4 | 9/20/10 |

# Issues/Concerns



- Cross-band confusion (e.g. strong Band 4 source contaminating weak Band 1 source)
- Detection sensitivity for source populations with "dropout" bands (especially for single-band objects such as cool brown dwarfs)
- Optimal window sizes for slowly-varying background estimation and confusion-noise estimation
- Detection performance for large extended objects (e.g. M31, Galactic plane)
- Detection performance for strong saturated sources
- Effect of non-isoplanicity on detection theshold -- variable sensitivity?
- Effects of pixel-to-pixel correlations and band-to-band electronic crosstalk