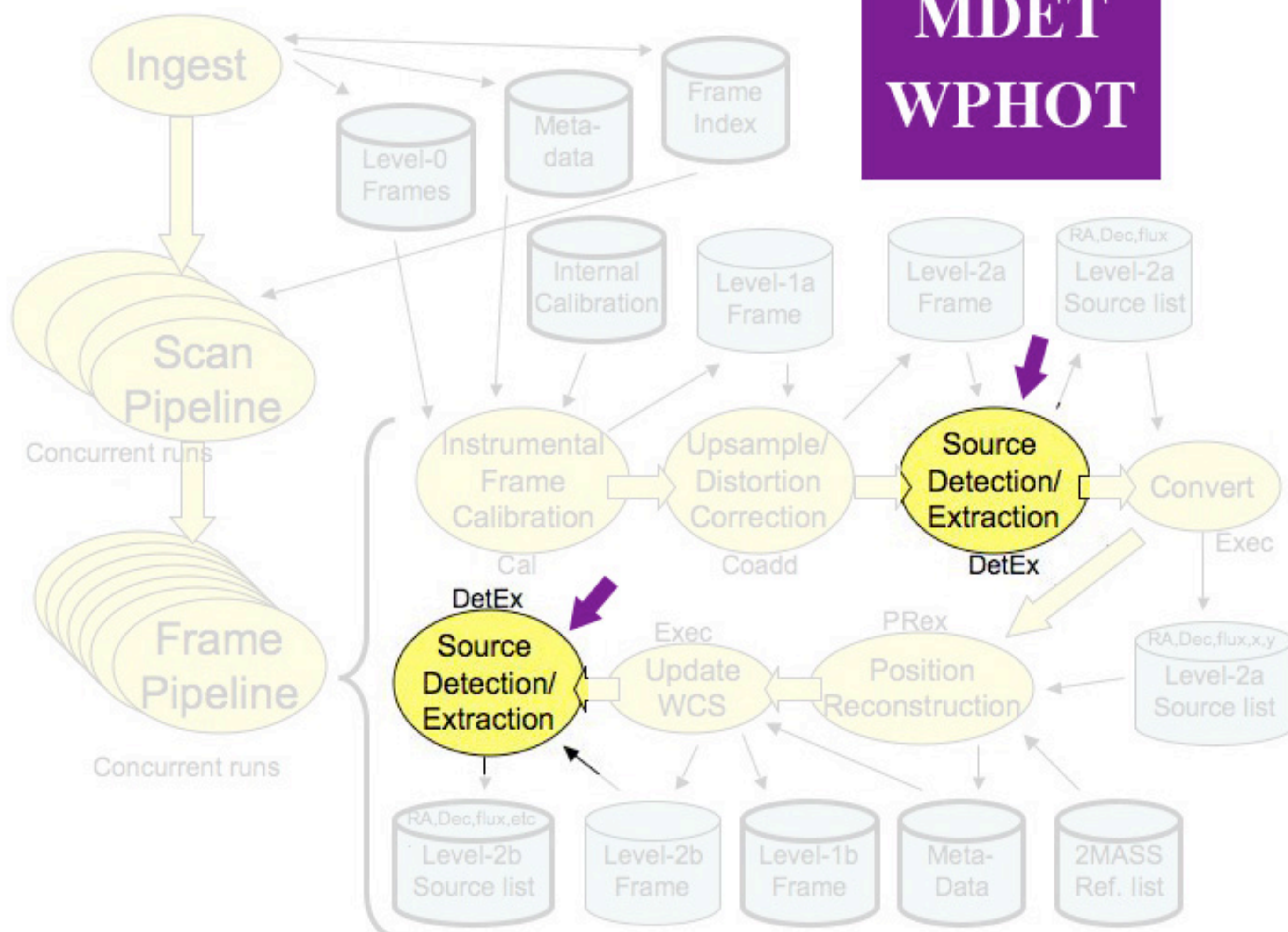
Source Detection

Multiband DETector (MDET)

Ken Marsh
IPAC/Caltech

WSDC Functional Block Diagram

DetEx:
MDET
WPHOT



Outline

- Relationship of MDET to other WSDS pipeline modules
- Why multiband?
- Theoretical basis
- Implementation
- Results of preliminary testing
- Peer review summary
- Development schedule
- Issues/concerns

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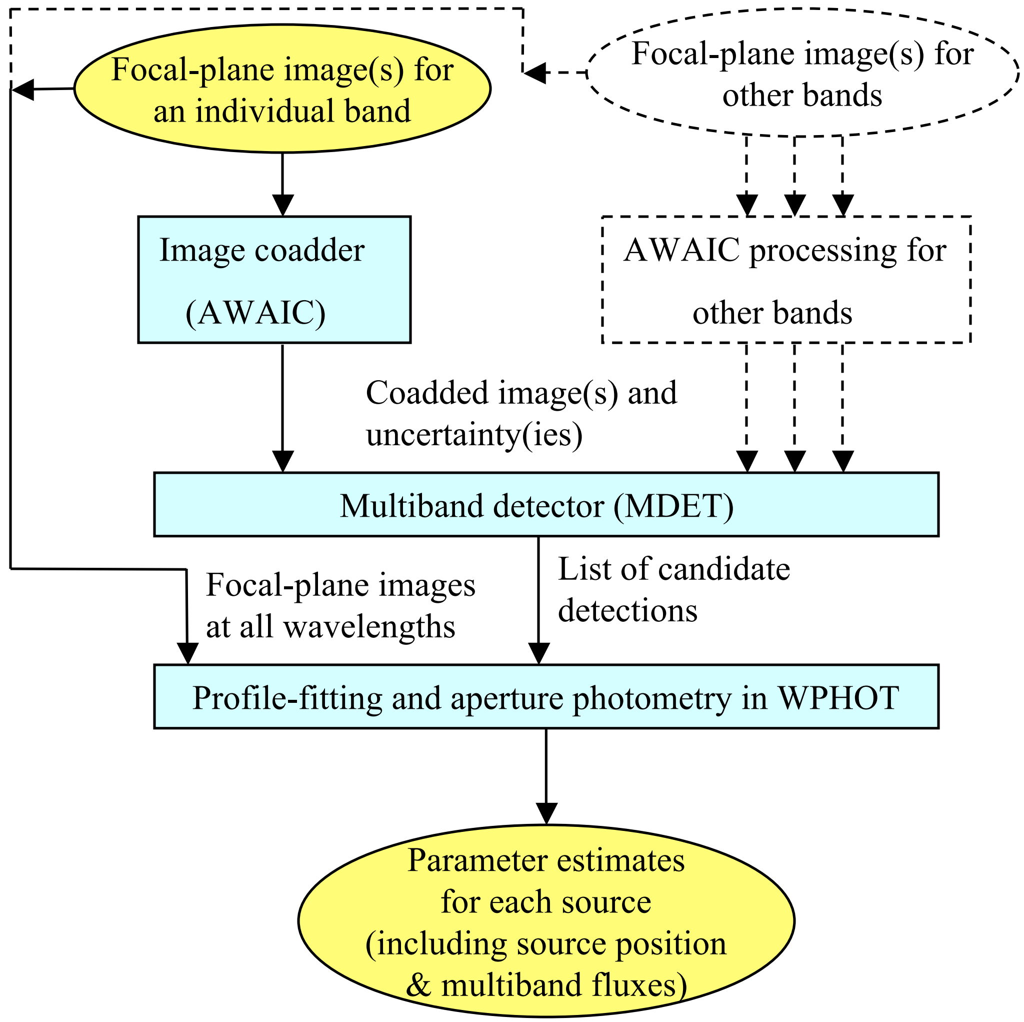
Jet Propulsion Laboratory
California Institute of Technology

Relationship to other WSDS pipeline modules



Advantages of multiband processing

- Increased sensitivity to weak sources due to the fact that detection is based on the stack of images at all bands
- 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
- 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

Mathematical derivation procedure:

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 maximum likelihood values (with non-negativity constraint on flux)
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:

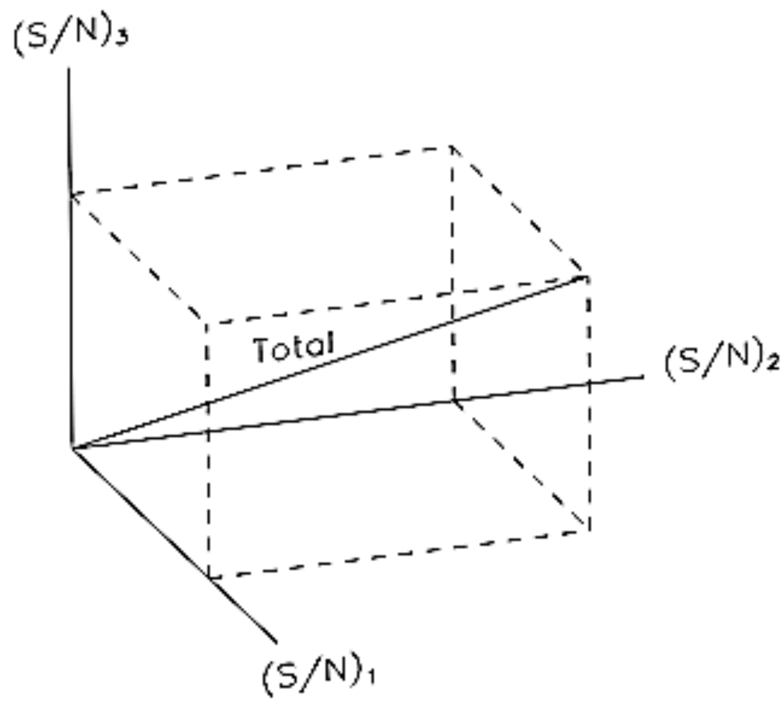
- Construct a *detection image* in units of sigma; the most likely locations of point sources correspond to local maxima in this image.

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

- 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 λ 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, λ) → **s**

Theoretical basis (continued)

A geometric interpretation of the combining of matched filter images at multiple bands:



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

MDET Procedure

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.

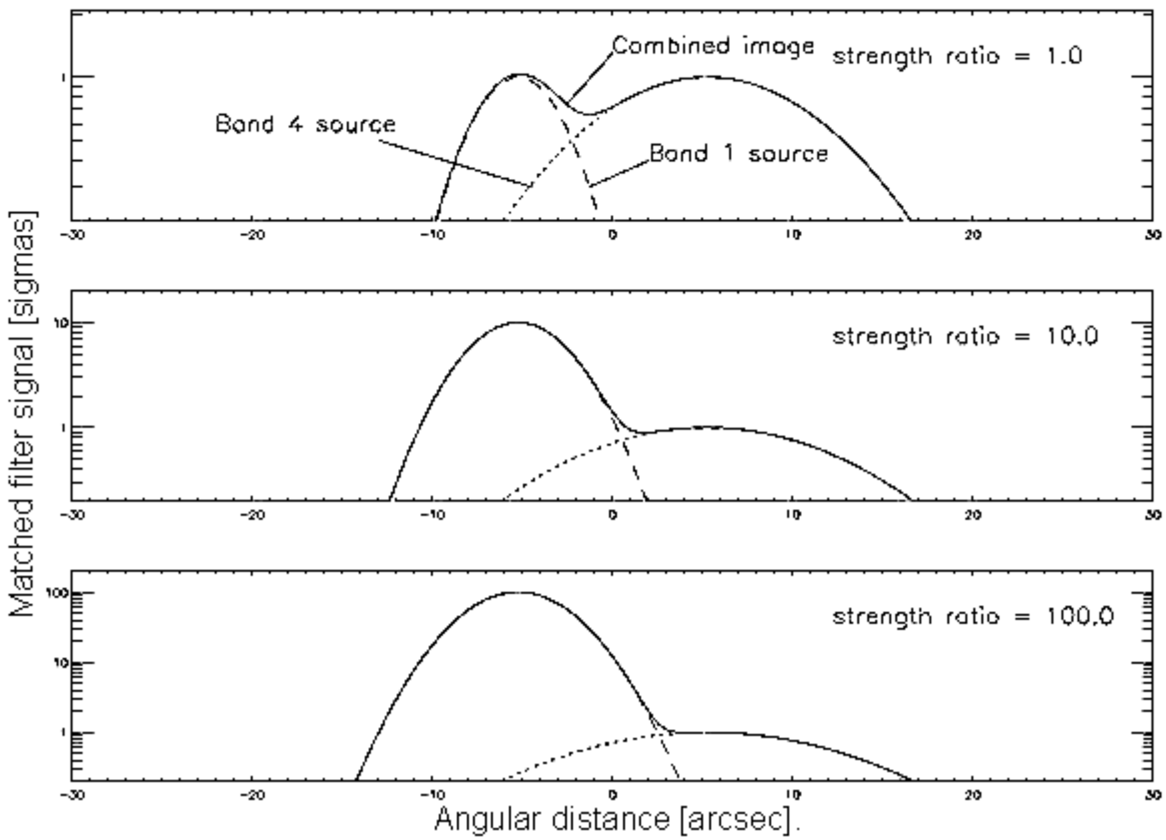
Procedure:

1. Subtract slowly-varying sky background from coadded image at each band.
2. Allow for 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.

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)

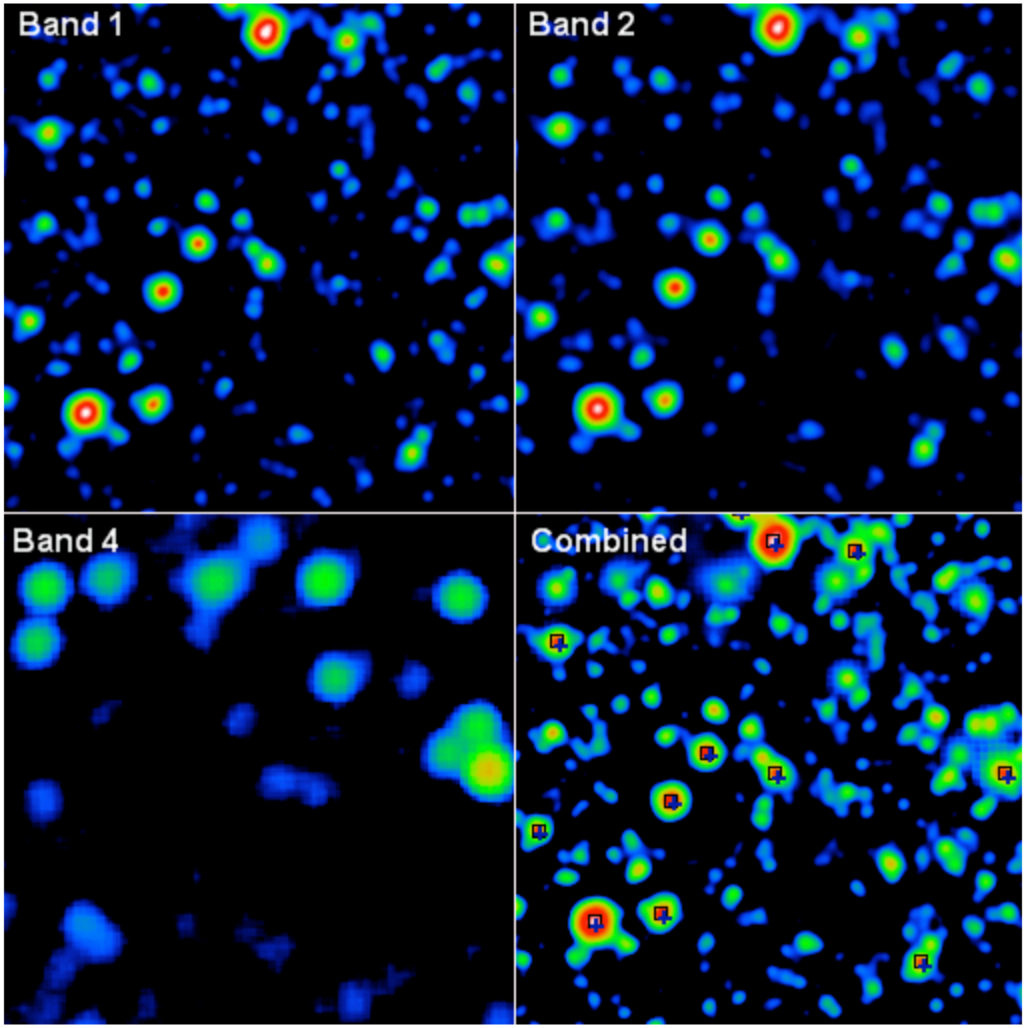
Options:

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.

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

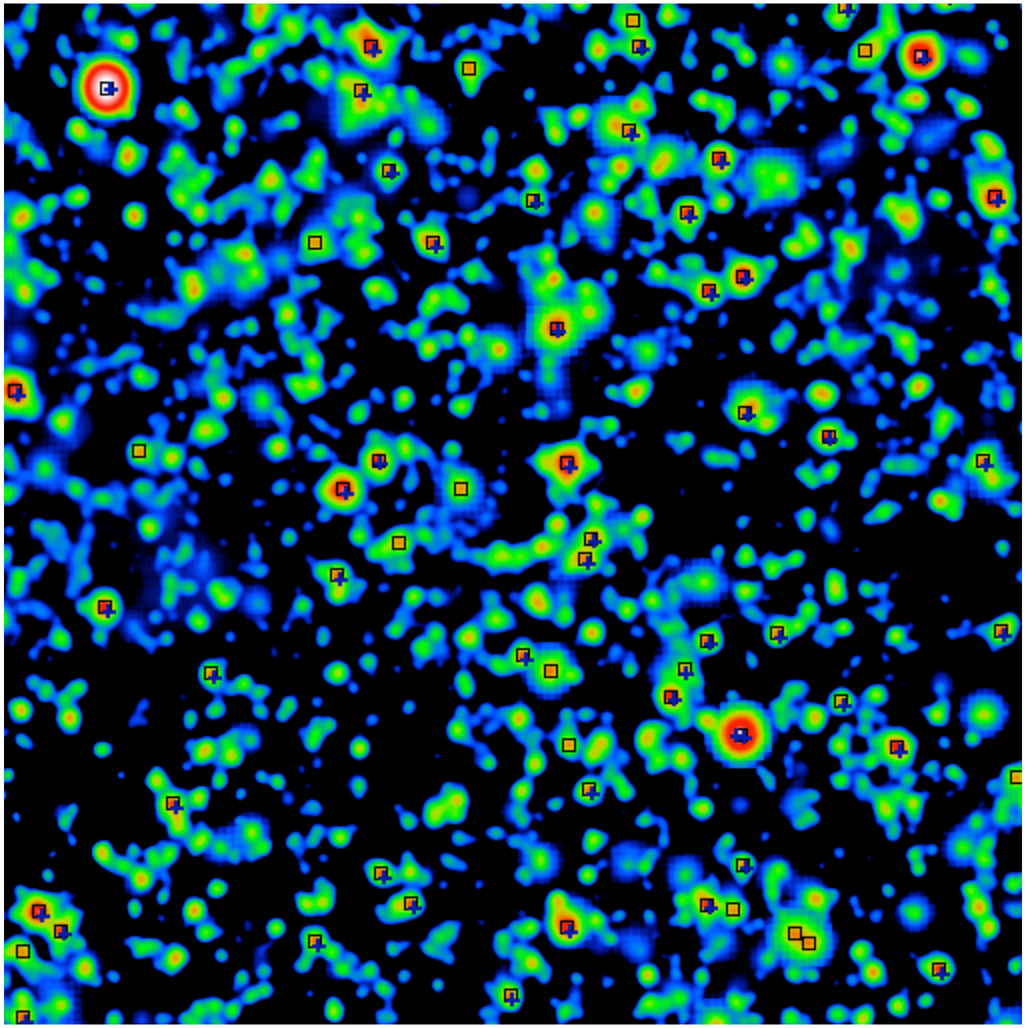
Subfield shown here:
5.9 x 5.9 arcmin

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 5s

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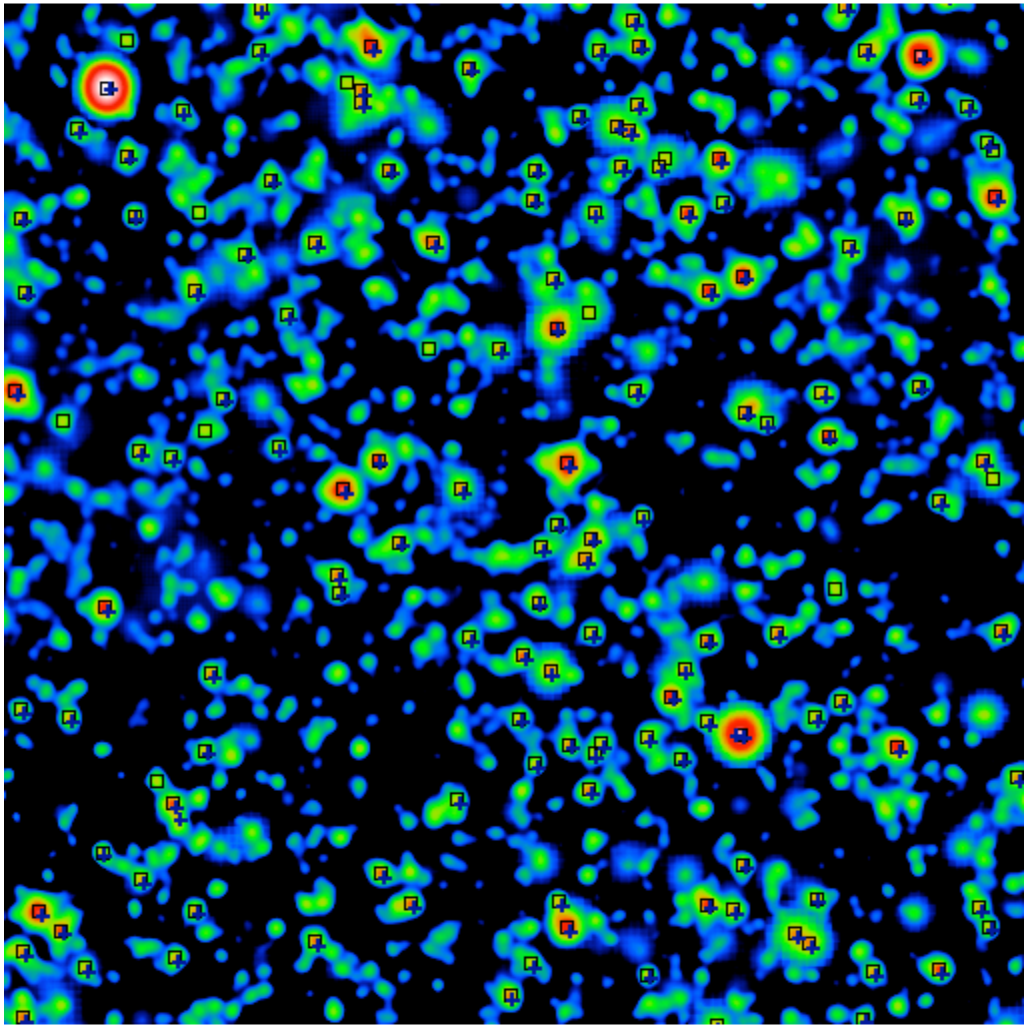
Galactic Center simulation (continued)

MDET



Detection
Threshold
3s

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 merging 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

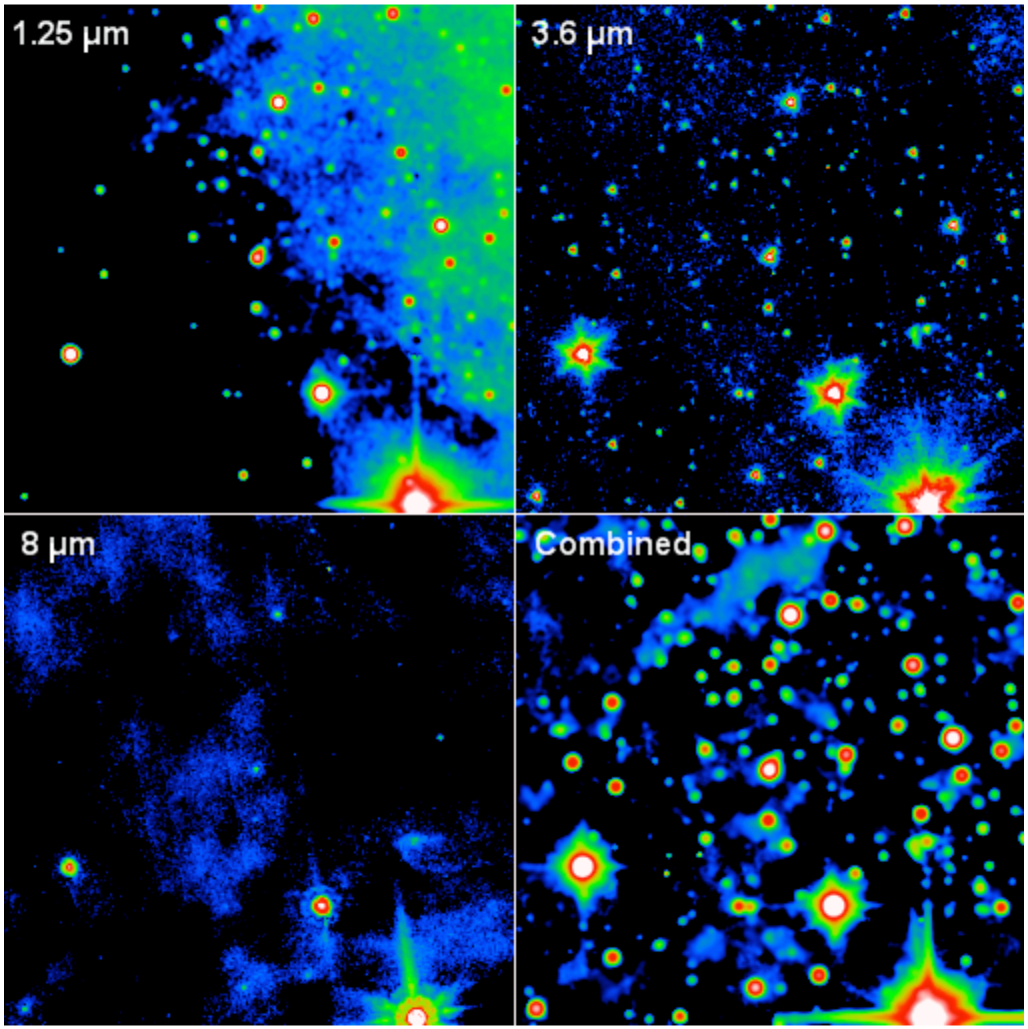
Tests with real data (2MASS + Spitzer IRAC)

- 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

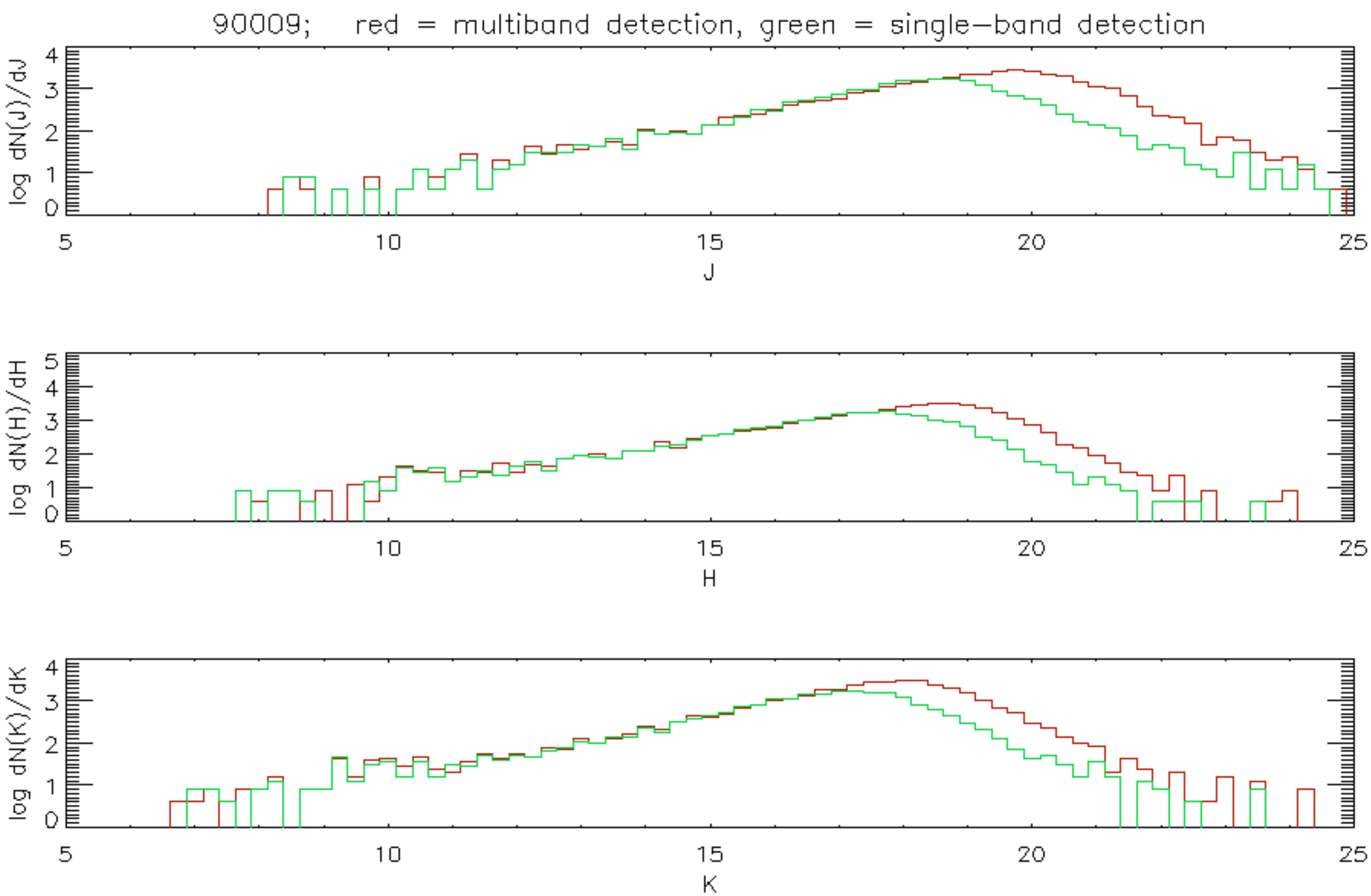
Example: ρ Oph core region



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



Peer Review Summary

Main issue of concern:

- Weak sources in bands 1-3 will be lost in the wings of strong 23 mm 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) --- debug code --- optimize parameters	Revised code + parameter set	v1.5	8/27/08
Fine tuning of parameters/code.	Optimized module	v2	12/17/08

Issues/Concerns

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