WSDC Subsystem Peer Review

Multiband DETector (MDET)

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Outline

- Relationship of MDET to other WSDS pipeline modules
- Why multiband?
- Theoretical basis
- Procedure
  - Steps involved
  - Allowance for confusion
  - Effect of blended sources
- Tests with synthetic (WISE) and real (2MASS + Spitzer) data.
- Remaining issues

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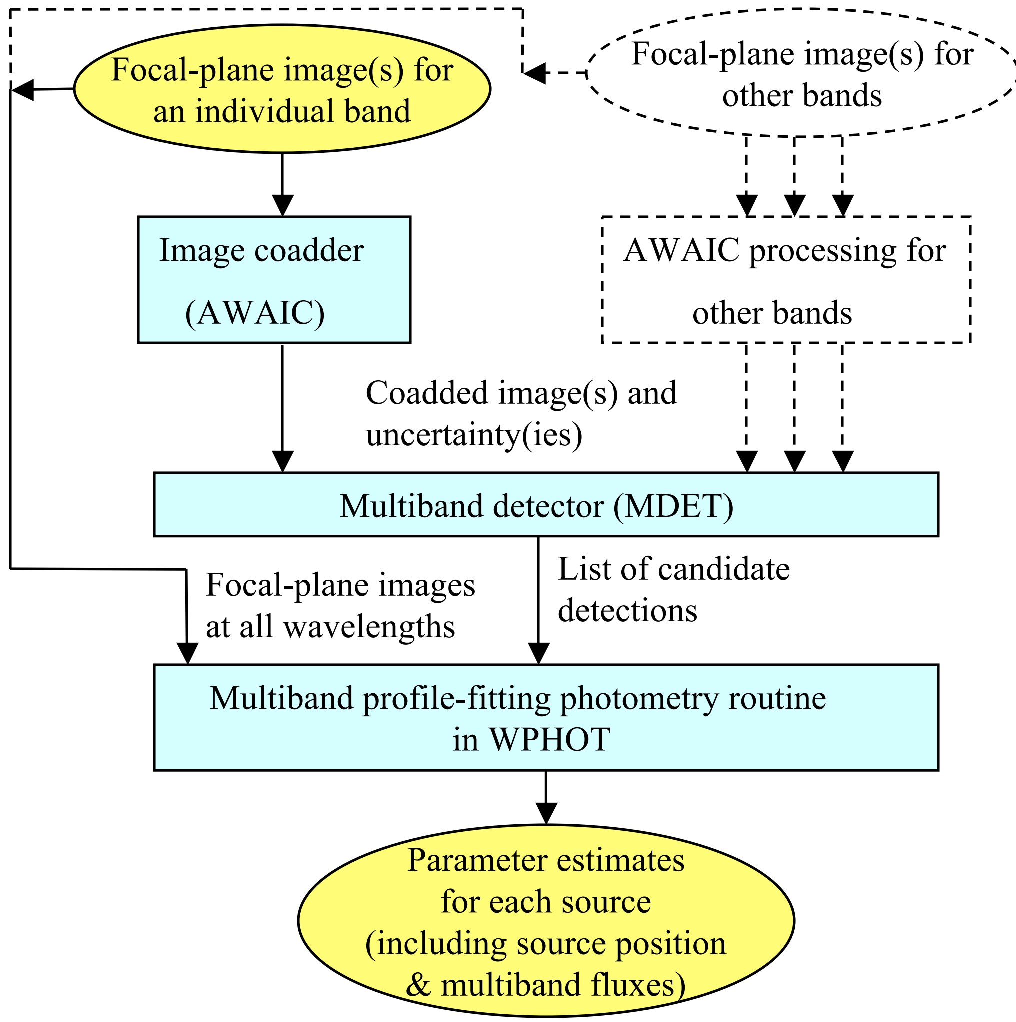
Relationship to other WSDS pipeline modules

MDET



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:

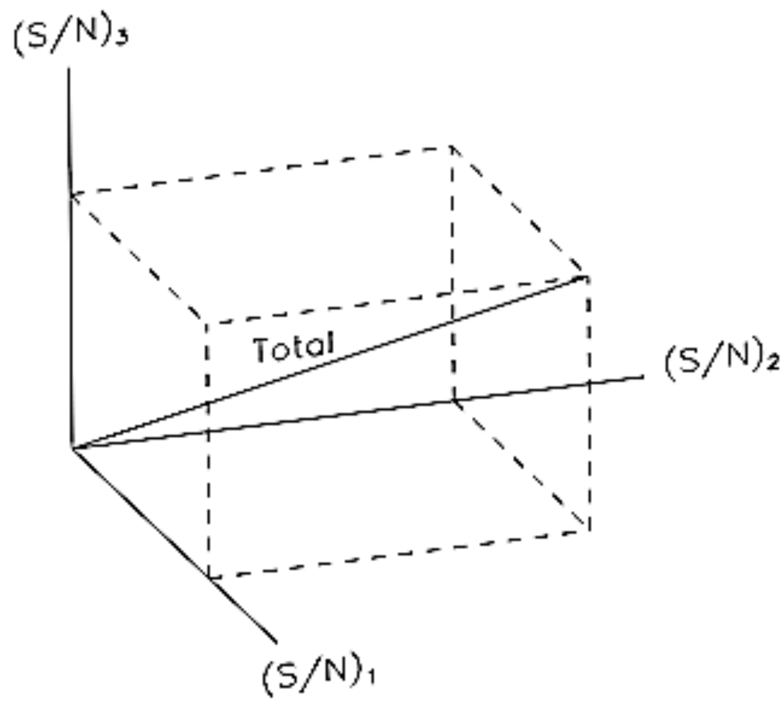
- Construct a *detection image* in units of sigma; the most likely locations of point sources correspond to local maxima in this image.

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

- 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) → **s**

Theoretical basis (continued)

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



MDET Procedure

Inputs:

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

Procedure:

1. Subtract slowly-varying sky background from coadded image at each band.
2. Calculate matched filter at each wavelength in units of S/N by dividing subtracted coadd image by the coadd uncertainty; set negative pixel values at zero (i.e., impose non-negativity constraint).
3. Combined matched filter images in quadrature.
4. List the positions and S/N values of all distinct local maxima which exceed the specified detection threshold.

Allowance for confusion

Definition: Spatially fluctuating background intensity due to sources which are not spatially resolvable by the measurement system or subsequent processing.

Procedure:

- Regard confusion as a separate component of additive noise, whose standard deviation, σ_{conf} , is estimated by:

  1. Calculating histogram of brightness fluctuations in a window of specified size in coadded image, and determining equivalent Gaussian distribution of equal area between the +/- 1σ points, assuming that the sources of interest are in the tail of this histogram.

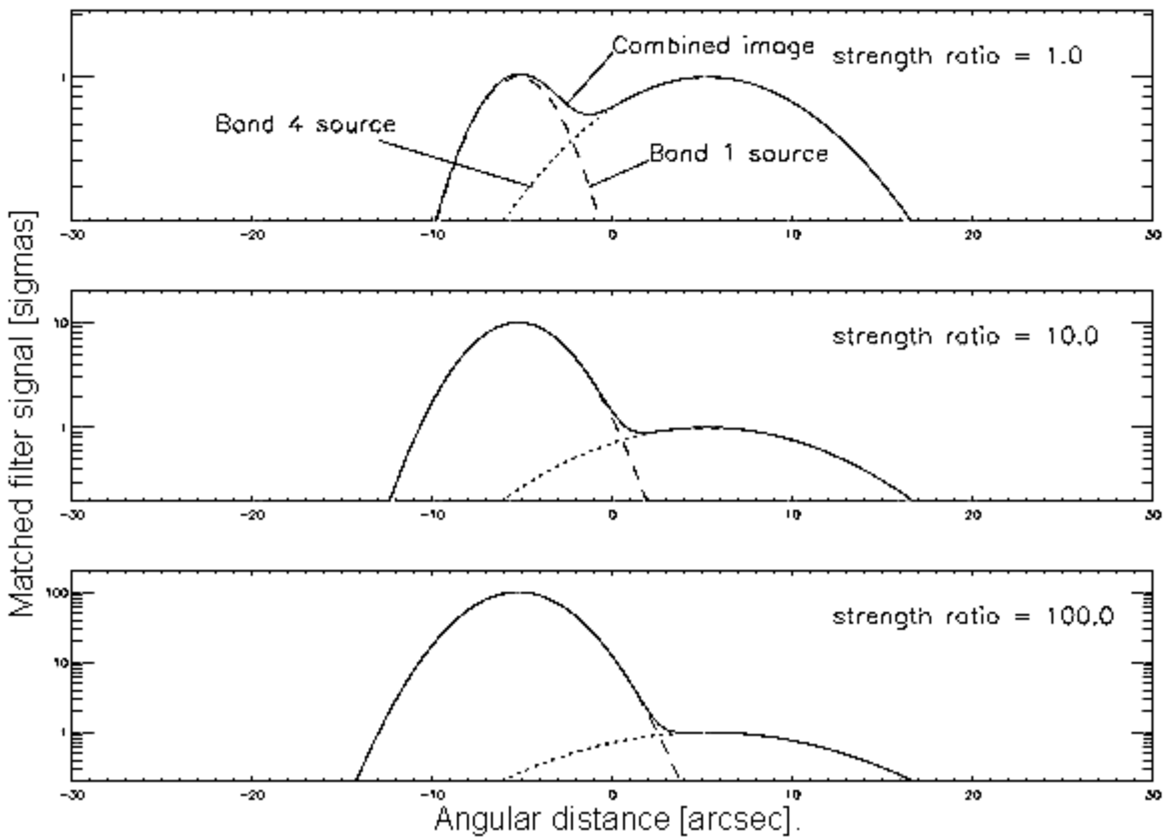
  2. Subtracting from s (in quadrature) the median value of coadd uncertainty within this window.
- Add the estimated σ_{conf} in quadrature to each pixel of the coadd uncertainty image in preparation for calculating the detection image.

Implication for detection: Constant S/N threshold => flux detection limit is raised in confused regions.

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)

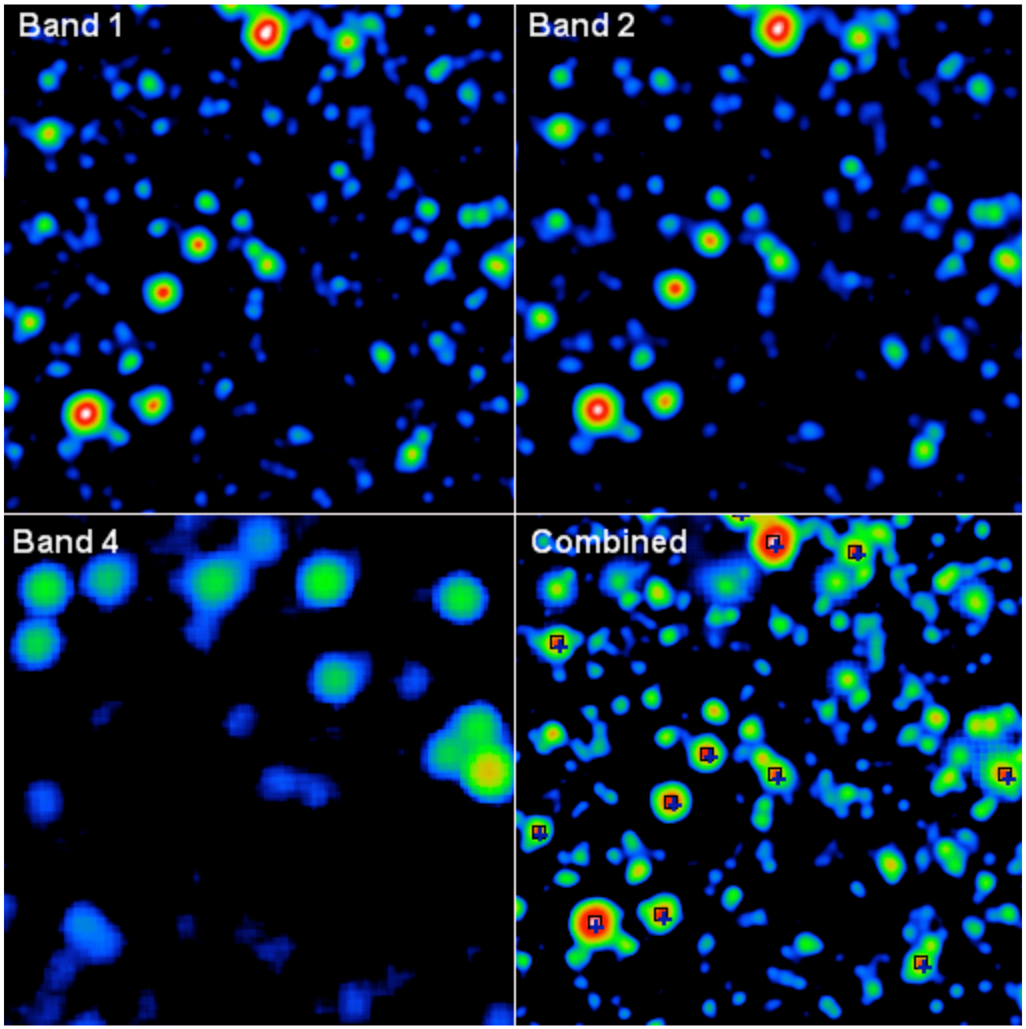
Options:

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
- Focal-plane distortion included
- Realistic additive noise

Galactic Center simulation



Field of view of simulation:
47 x 47 arcmin

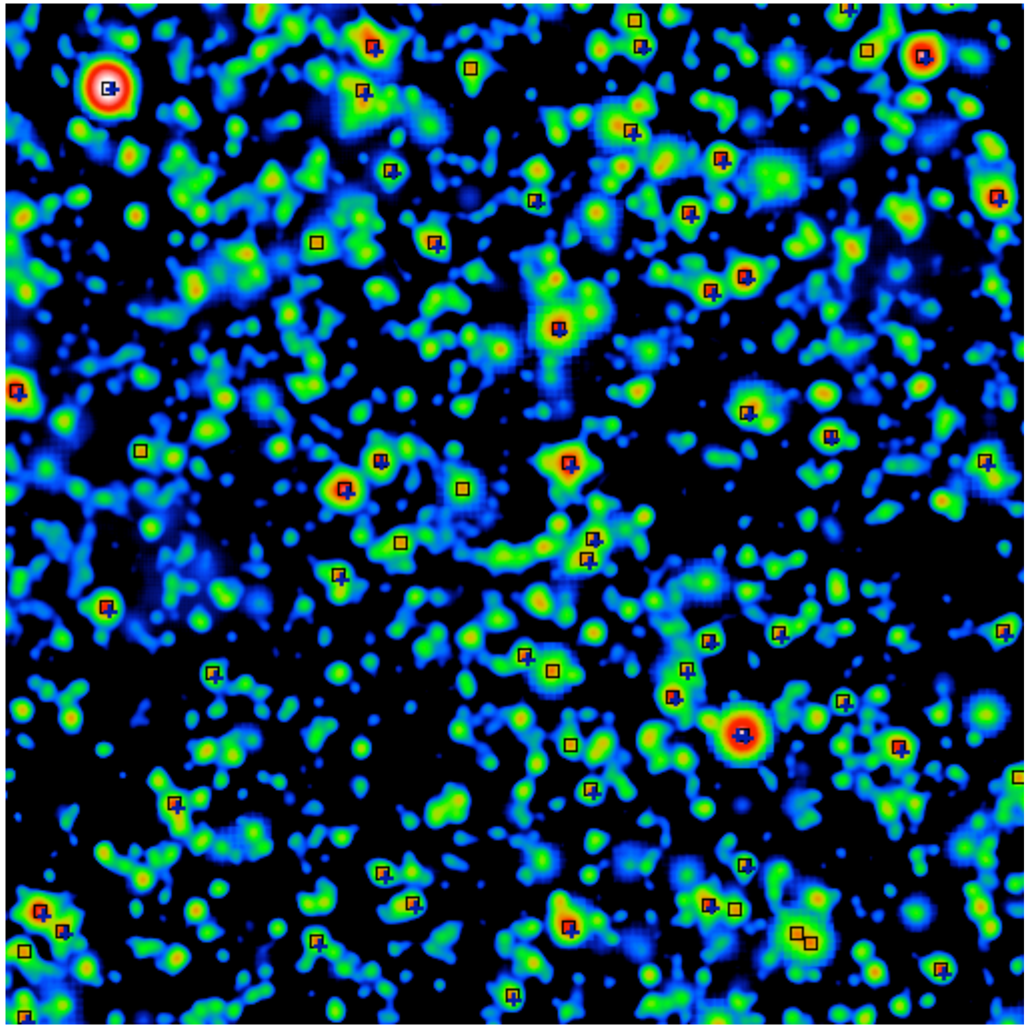
Subfield shown here:
5.9 x 5.9 arcmin

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

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

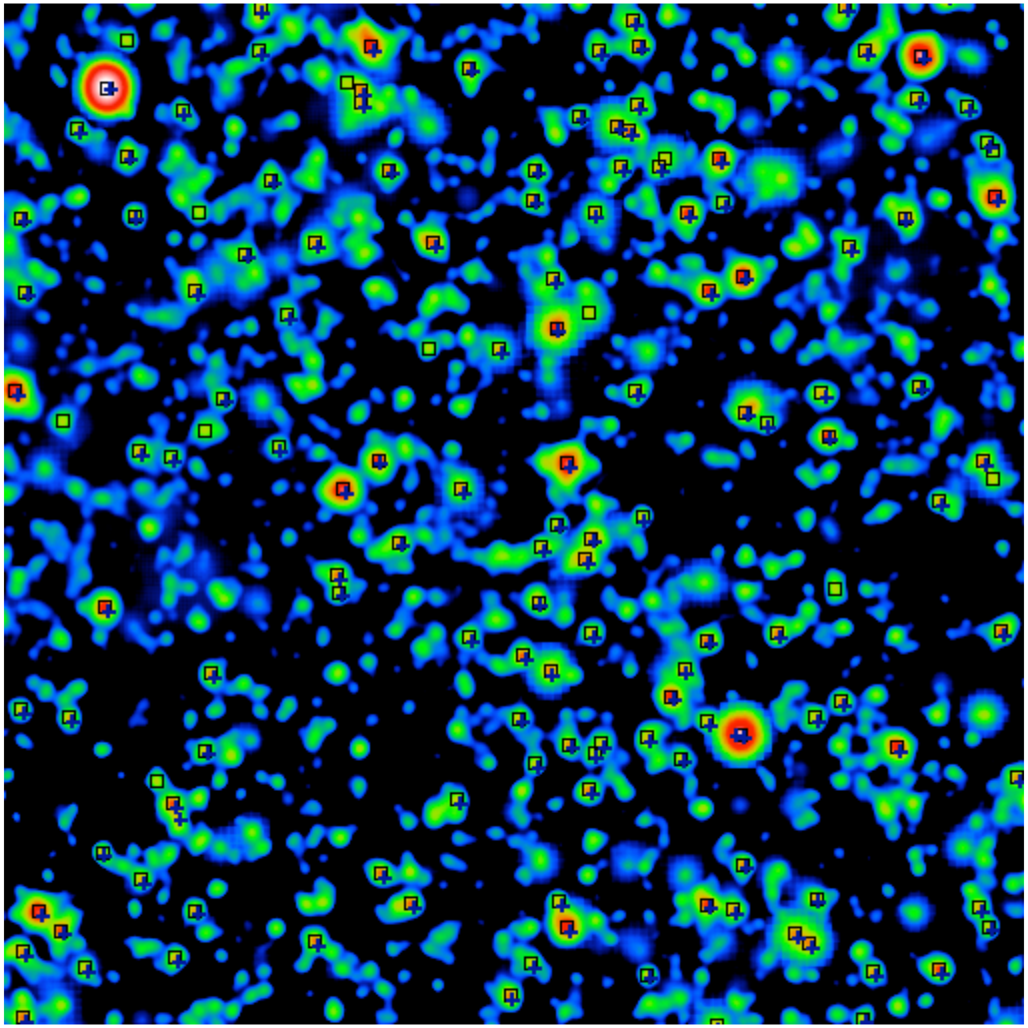
Galactic Center simulation (continued)

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



Detection Threshold 5s

Galactic Center simulation (continued)



Detection Threshold
3s

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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

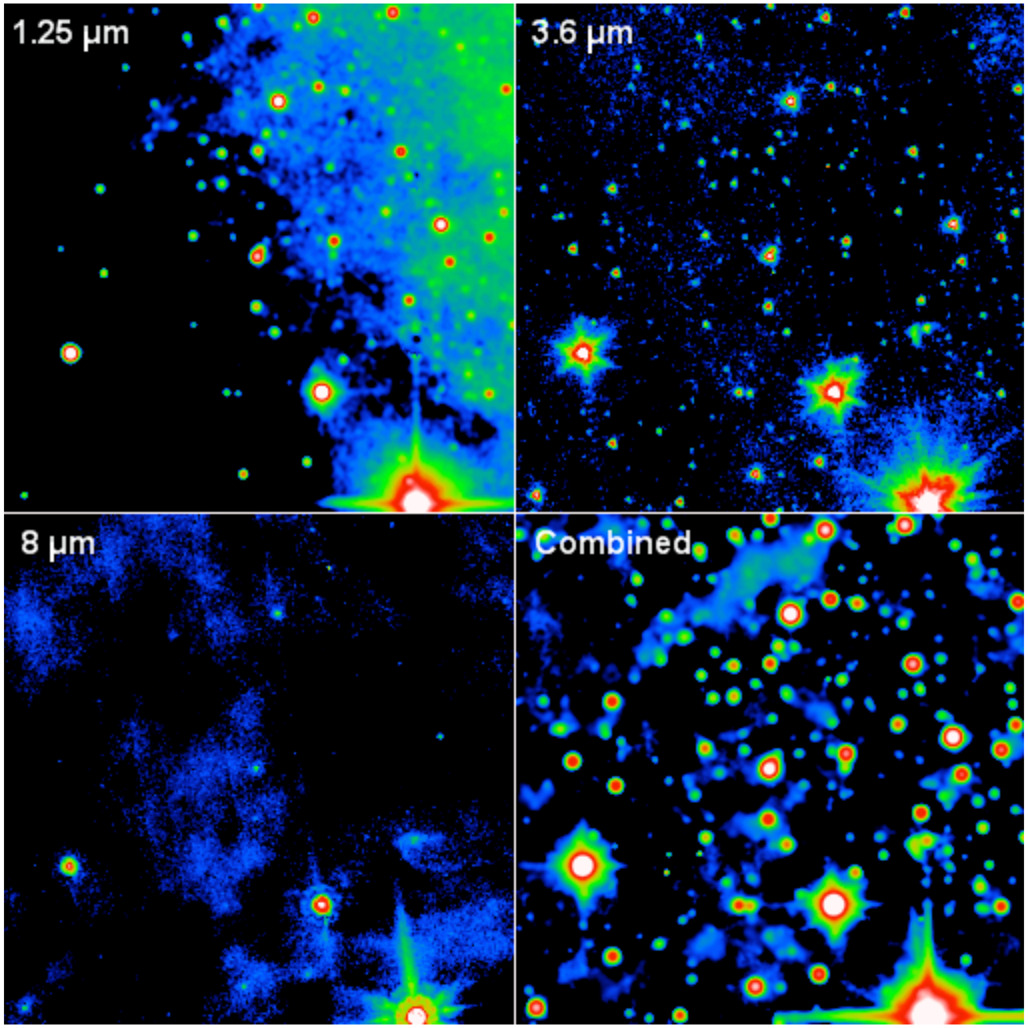
Tests with real data (2MASS + Spitzer IRAC)

- 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: r Oph core region



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

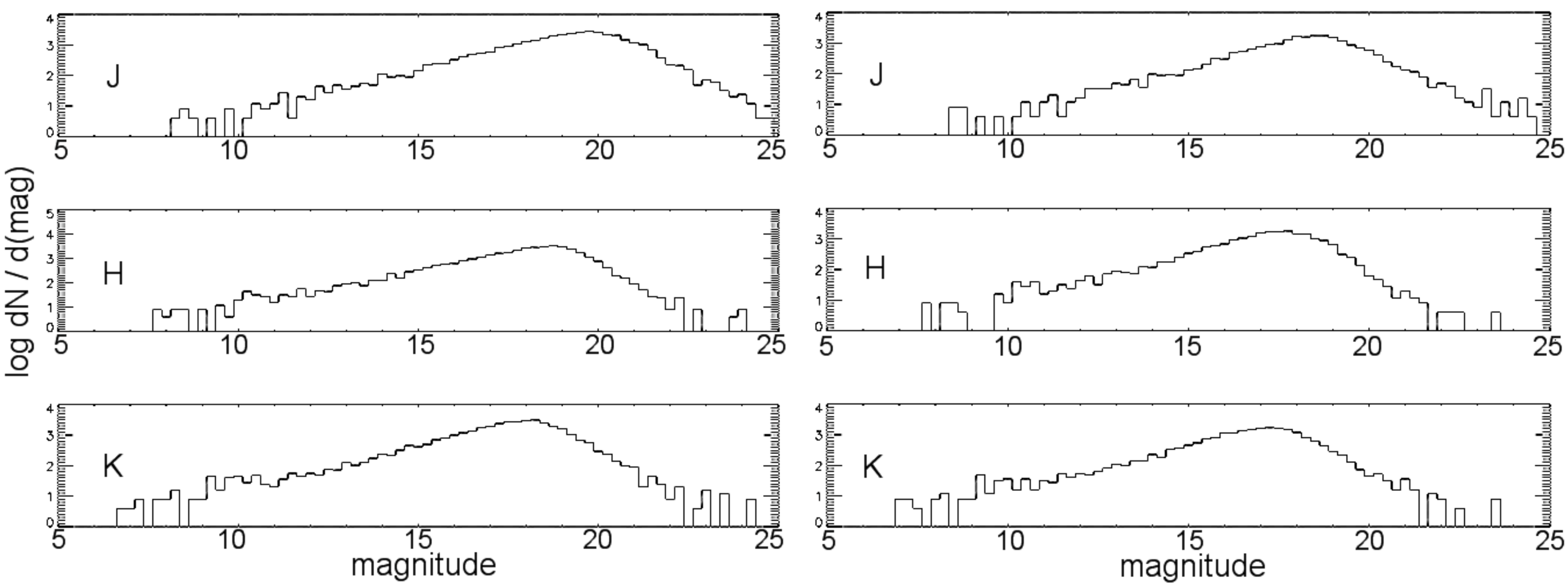
Field of view:
4.3 x 4.3 arcmin

r Oph source counts

MDET

Using multiband detection

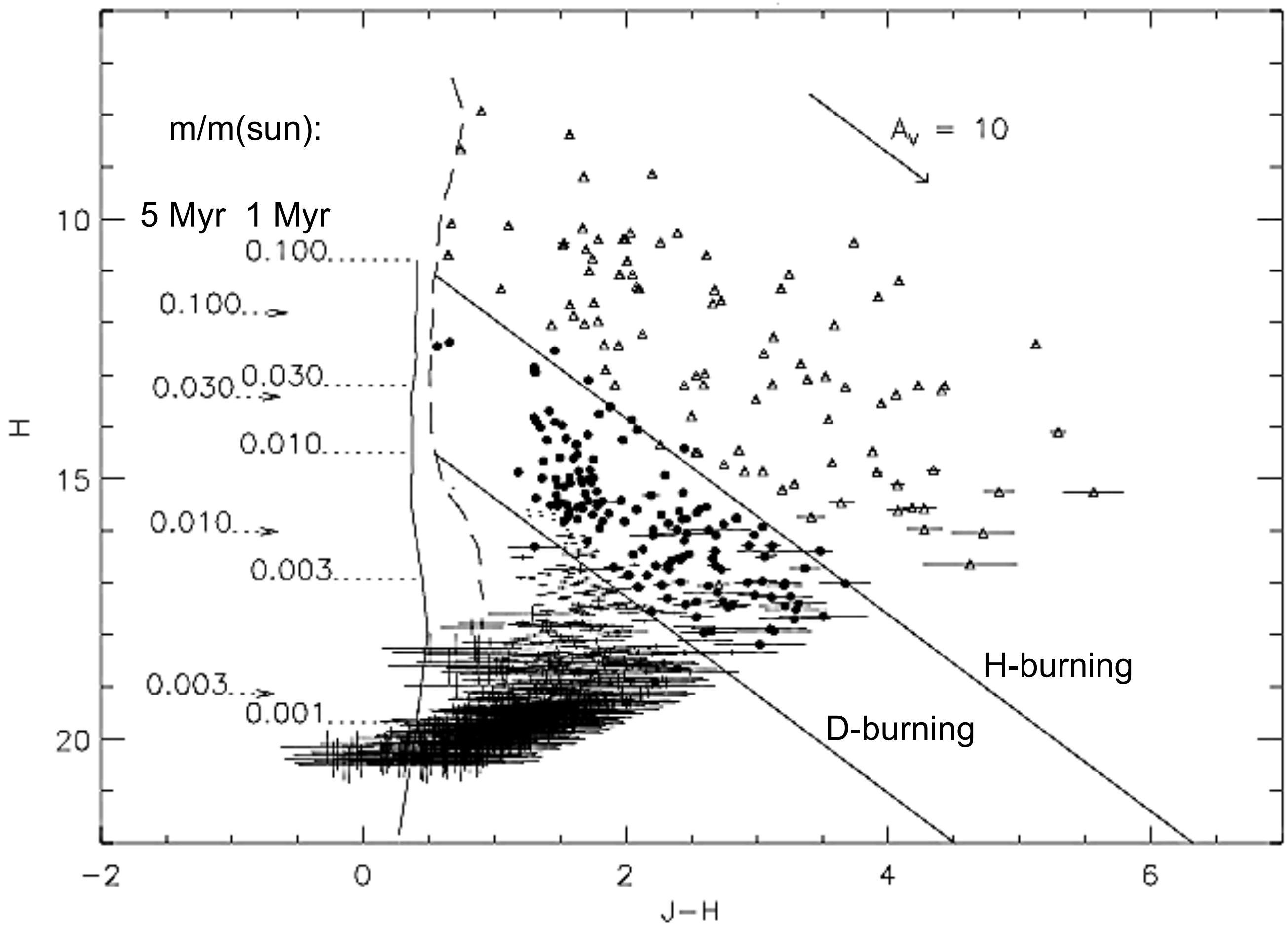
Using single-band detection
(2MASS Extended Mission release)



r Oph color-magnitude (H vs. J-H)

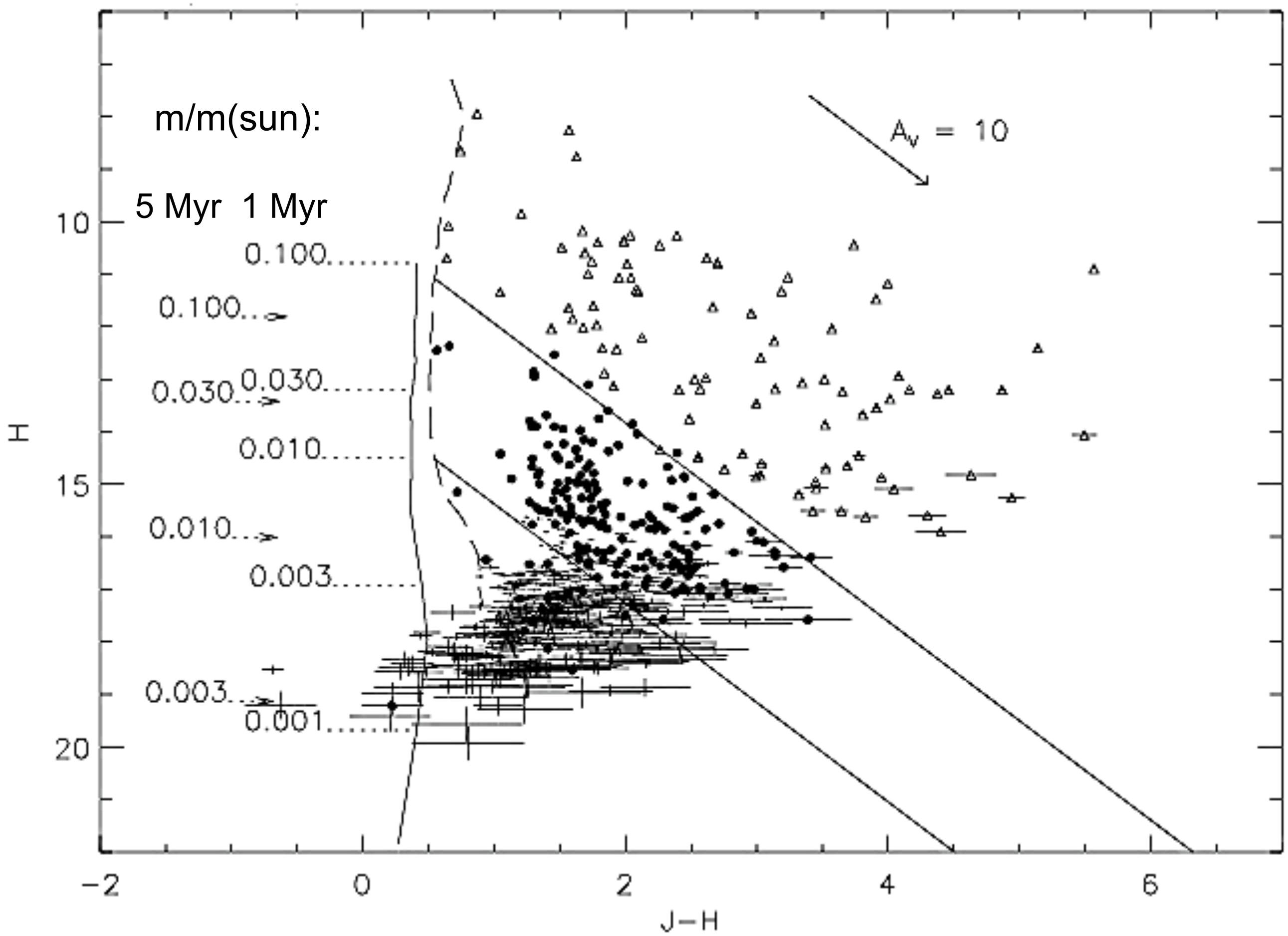
Based on multiband detection/photometry.

Flux SNR > 3



r Oph color-magnitude (H vs. J-H)

Based on single-band detection & aperture photometry.
(2MASS Extended Mission release). Flux SNR > 3



Remaining issues

- Optimal window sizes for slowly-varying background estimation & confusion estimation
- Effect of large extended objects (e.g. M31, Galactic plane)
- Effect of strong saturated sources
- Effect of non-isoplanicity on detection threshold
- Effects of pixel-to-pixel correlations and band-to-band electronic crosstalk.