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WISE Photometry (WPHOT)

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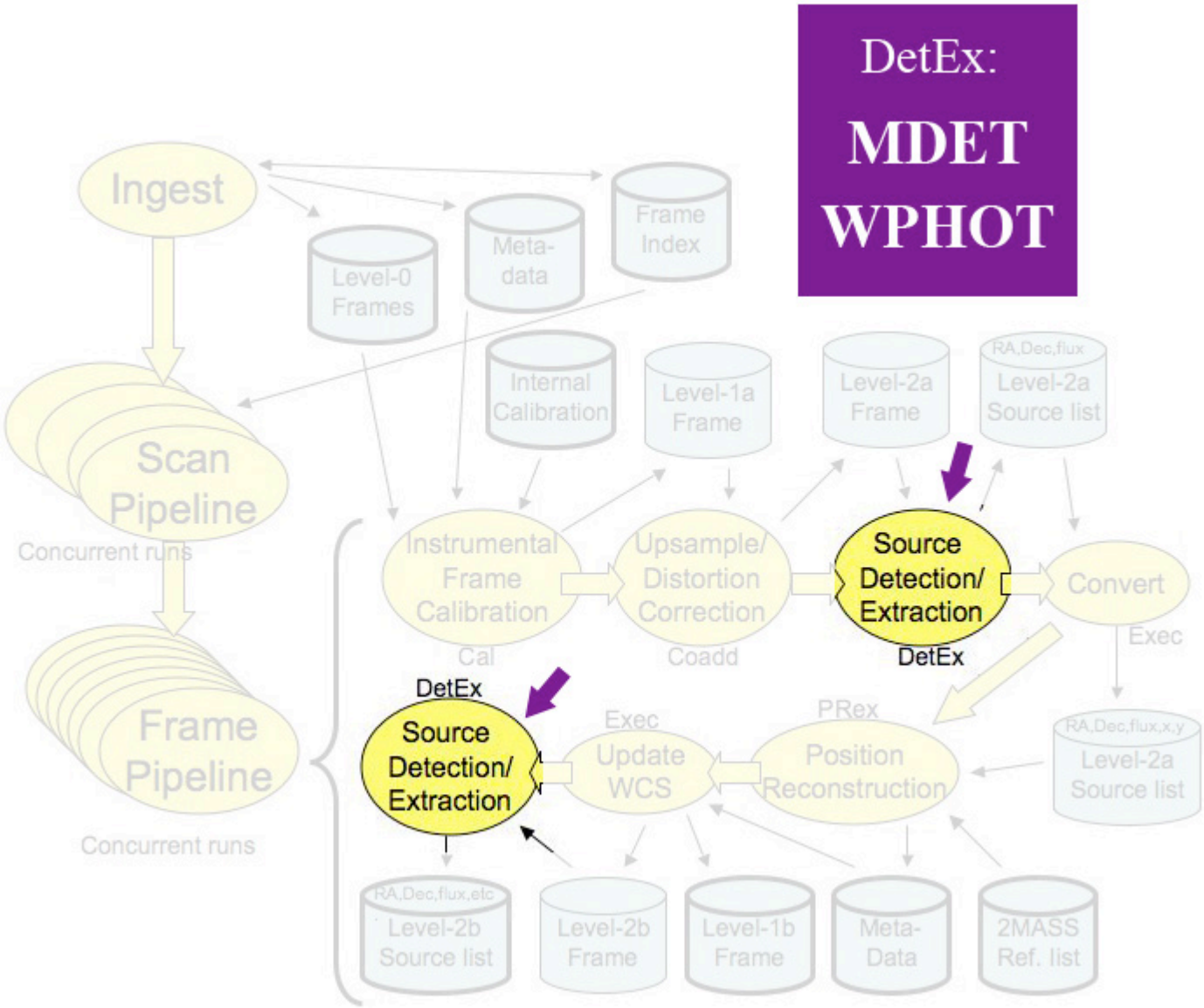
Overview

WPHOT is designed to perform the source characterization associated with each of the three stages of source extraction during pipeline processing (single-frame, single-epoch 4-band frameset, and final coadd stage).

The characterization is based on an input list of source candidate positions produced by MDET using a detection algorithm which makes use of the data at all bands simultaneously.

- Profile-fitting (WPRO)
- Aperture Photometry & Characterization (WAPP)

WSDC Functional Block Diagram



Driving Requirements - 1

- [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 shall 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, where the noise includes flux errors due to zodiacal foreground emission, instrumental effects, source photon statistics, and neighboring sources. This requirement shall not apply to sources that are superimposed on an identified artifact.

Driving Requirements - 2

- [L4WSDC-010] The final WISE Source Catalog shall include sources down to SNR=5 in any band, and the completeness and reliability of sources in the Catalog shall be characterized at all flux levels.
- [L4WSDC-012] Flux measurements in the WISE Source Catalog shall have a SNR of five or more for point sources with fluxes of 0.12, 0.16, 0.65 and 2.6 mJy at 3.3, 4.7, 12 and 23 μm, respectively, assuming 8 independent exposures and where the noise flux errors due to zodiacal foreground emission, instrumental effects, source photon statistics, and neighboring sources.
- [L4WSDC-013] The root mean square error in relative photometric accuracy in the WISE Source Catalog shall be better than 7% in each band for unsaturated point sources with SNR>100, where the noise flux errors due to zodiacal foreground emission, instrumental effects source photon statistics, and neighboring sources. This requirement shall not apply to sources that superimposed on an identified artifact.

Driving Requirements - 3

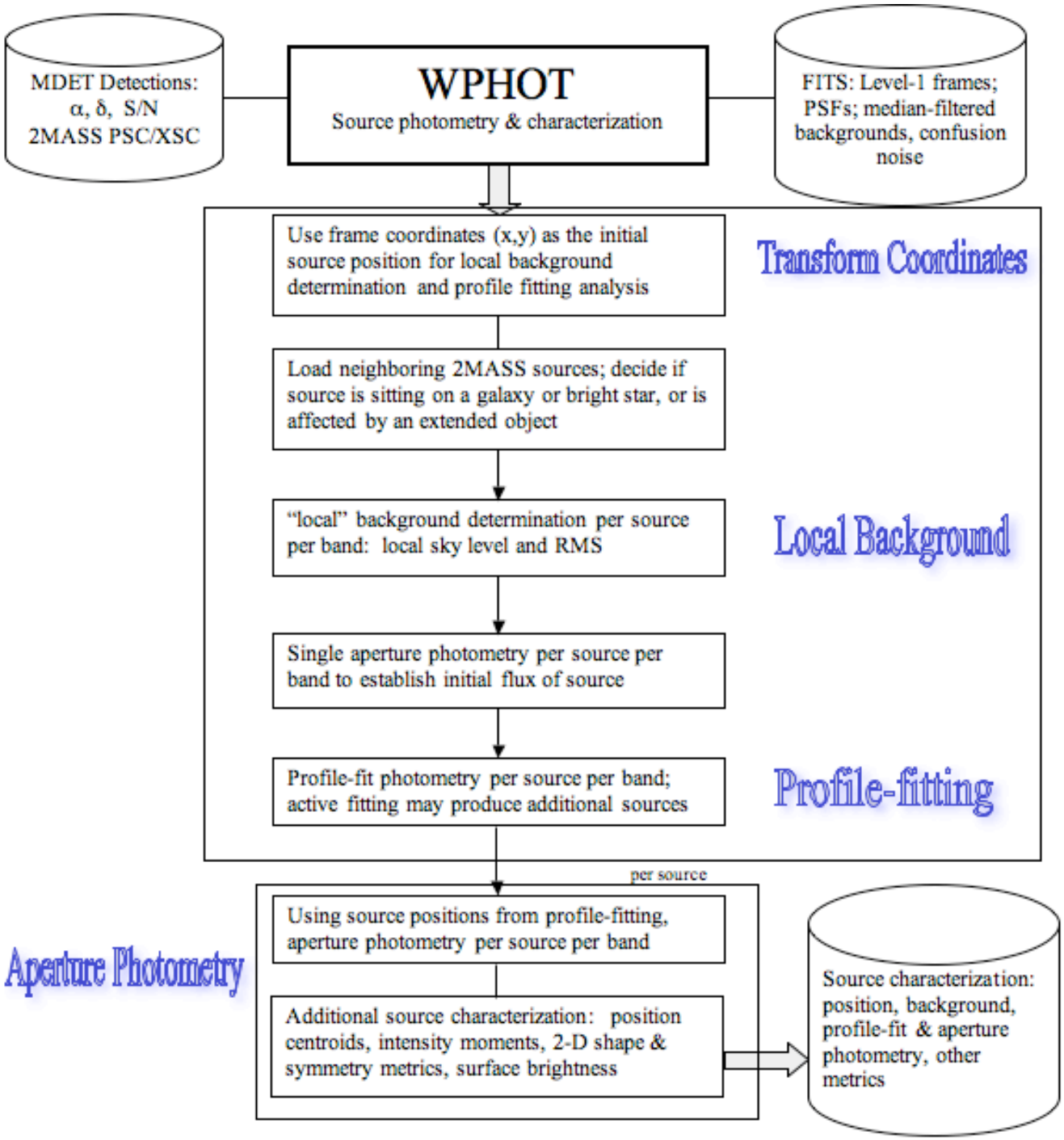
- [L4WSDC-015] The WISE Source Catalog shall contain the measured in-band fluxes or flux upper-limits in the four WISE bands for objects detected in at least one band in the WISE Atlas Images.

- [L4WSDC-016] The WISE Source Catalog shall contain uncertainties in the flux measurements (one sigma) in all bands for which a source is detected.

- [L4WSDC-018] The WISE Source Catalog shall contain uncertainties in the coordinates measurements for each object.

Driving Requirements - 4

- [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.


MDET Detections:
α, δ, S/N
2MASS PSC/XSC
WPHOT
Source photometry & characterization
FITS: Level-1 frames; PSFs; median-filtered backgrounds, confusion noise
Use frame coordinates (x,y) as the initial source position for local background determination and profile fitting analysis
Transform Coordinates
Load neighboring 2MASS sources; decide if source is sitting on a galaxy or bright star, or is affected by an extended object
"local" background determination per source per band: local sky level and RMS
Local Background
Single aperture photometry per source per band to establish initial flux of source
Profile-fit photometry per source per band; active fitting may produce additional sources
Profile-fitting
per source
Using source positions from profile-fitting, aperture photometry per source per band
Additional source characterization: position centroids, intensity moments, 2-D shape & symmetry metrics, surface brightness
Aperture Photometry
Source characterization: position, background, profile-fit & aperture photometry, other metrics

Profile-Fitting Photometry (WPRO)

- Based on maximum likelihood fit of PSFs to pixel values at all bands simultaneously
- Advantages of multiband fit:
  1. High resolution data at short wavelengths can guide the fitting procedure at the longer wavelengths where the resolution is poorer
  2. No post-extraction bandmerge step is required, thus avoiding cross-band matching ambiguities in crowded fields

Models for maximum likelihood estimation

Measurement model:

$$\rho_{\lambda i} = \sum_{n=1}^{N_B} (f_\lambda)_n H_\lambda(\mathbf{r}_{\lambda i} - \mathbf{s}_n) + b_\lambda + \nu_{\lambda i}$$

pixel value — flux — PSF — background — noise

Noise model:

$$\sigma^2_{\lambda i} = (\rho_{\lambda i} - b_\lambda)/g_\lambda + [(\rho_{\lambda i} - b_\lambda)(\sigma_{\mathrm{ff}})_\lambda]^2 + (N_R)^2_\lambda$$

[Poisson noise] [Flat-fielding error] [Read noise]

$$+ (\sigma_b)^2_\lambda + [(f_{\mathrm{ap}})_\lambda \delta H_\lambda(\mathbf{r}_{\lambda i} - \mathbf{s}_n)]^2$$

[background noise] [PSF error]

Solution procedure

Construct parameter vector:

$$\mathbf{z} \equiv [\{\mathbf{s}_n, \{(f_\lambda)_n : \lambda = 1, \ldots N_\lambda\} : n = 1, \ldots N_\mathrm{B}\}]$$

[Position of *n*th blend component]

[fluxes at the multiple bands]

Maximize:

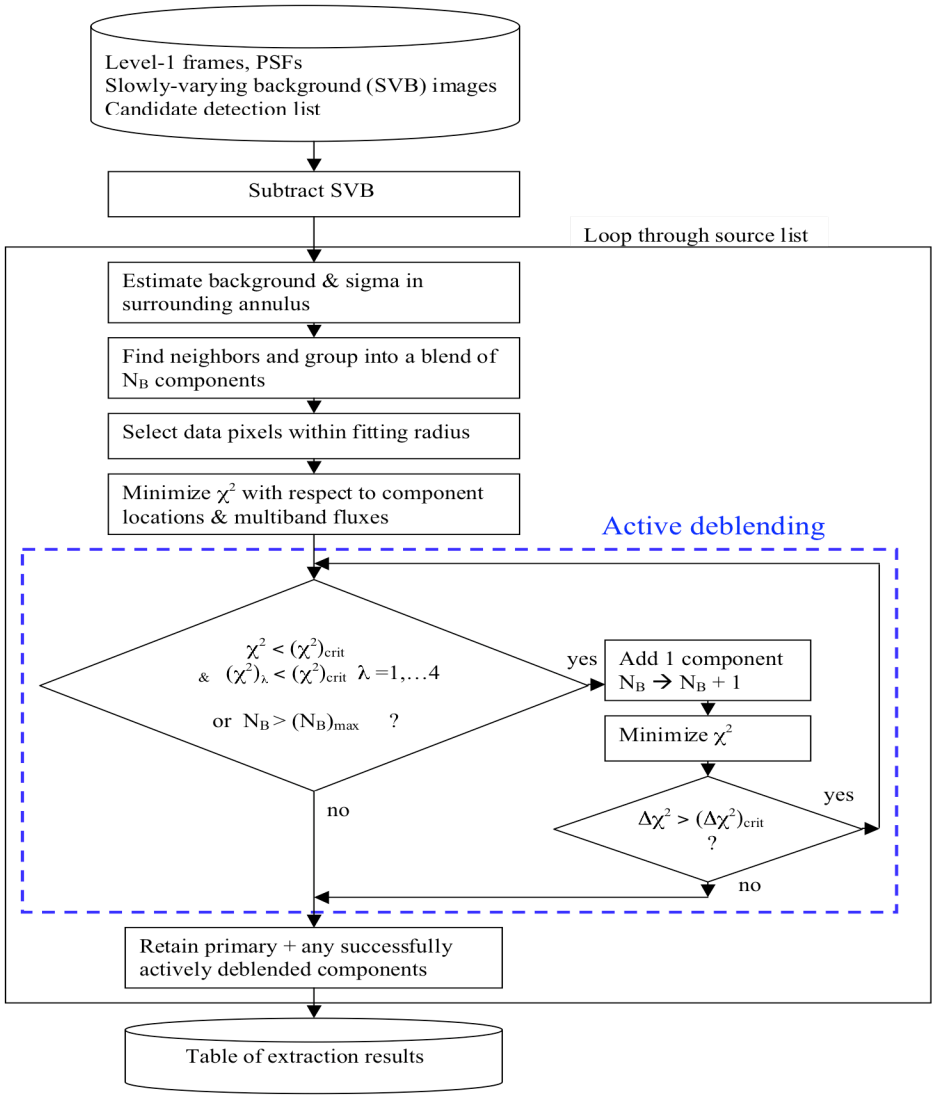
$$\ln P(\rho|\mathbf{z}, N_\mathrm{B}) = -\frac{1}{2}\sum_\lambda\sum_i \frac{1}{\sigma^2_{\lambda i}}[\rho_{\lambda i} - b_\lambda - \sum_{n=1}^{N_\mathrm{B}}(f_\lambda)_n H_\lambda(\mathbf{r}_{\lambda i} - \mathbf{s}_n)]^2 + \mathrm{const.}$$

Evaluate quality of fit:

$$\chi^2_\nu = \frac{1}{N_\mathrm{obs} - n_\mathrm{p}}\sum_\lambda\sum_i \frac{1}{\sigma^2_{\lambda i}}[\rho_{\lambda i} - b_\lambda - \sum_{n=1}^{N_\mathrm{B}}(\hat{f}_\lambda)_n H_\lambda(\mathbf{r}_{\lambda i} - \hat{\mathbf{s}}_n)]^2$$

Estimated fluxes and positions

WPRO flow

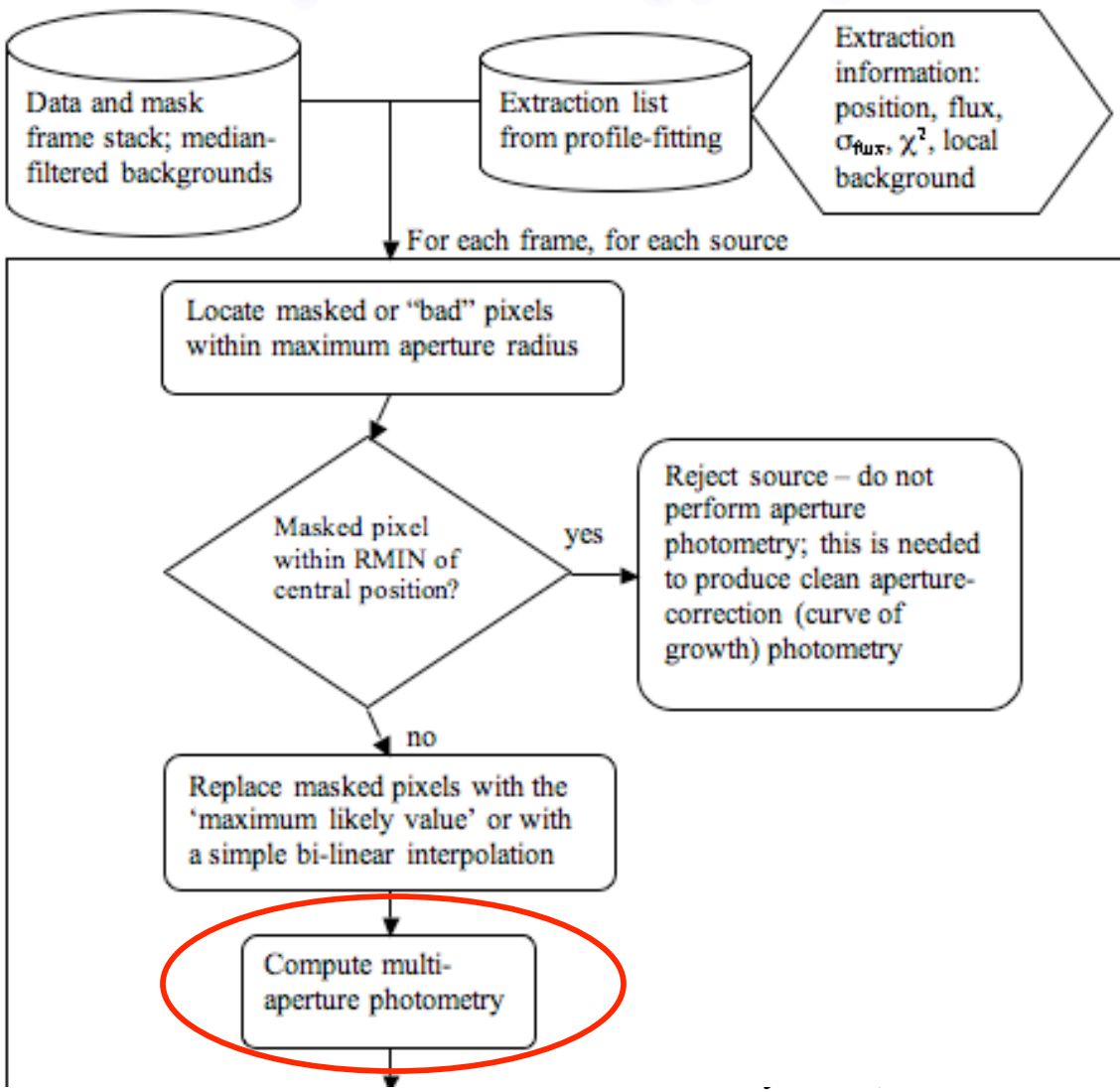

Level-1 frames, PSFs
Slowly-varying background (SVB) images
Candidate detection list
Subtract SVB
Loop through source list
Estimate background & sigma in surrounding annulus
Find neighbors and group into a blend of N_B components
Select data pixels within fitting radius
Minimize χ^2 with respect to component locations & multiband fluxes
Active deblending
$\chi^2 < (\chi^2)_{crit}$ & $(\chi^2)_\lambda < (\chi^2)_{crit}$ $\lambda = 1,\ldots 4$ or $N_B > (N_B)_{max}$?
yes
Add 1 component $N_B \rightarrow N_B + 1$
Minimize χ^2
$\Delta\chi^2 > (\Delta\chi^2)_{crit}$?
yes
no
no
Retain primary + any successfully actively deblended components
Table of extraction results

Aperture Photometry

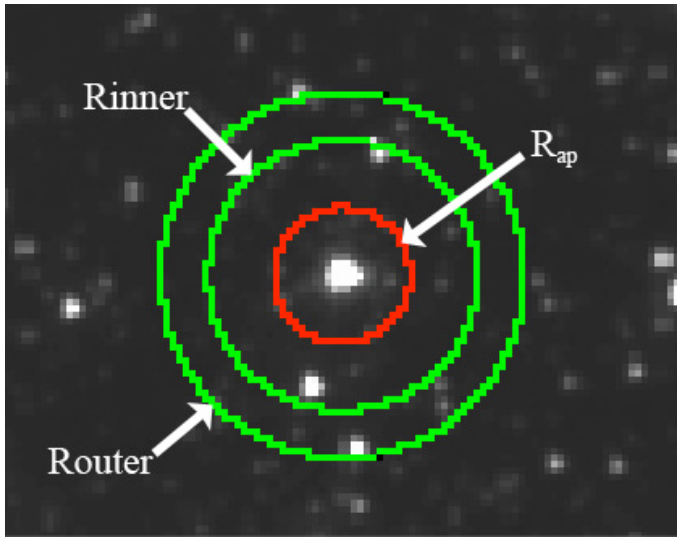
The Aperture Photometry System (WAPP) performs multi-aperture photometry and additional source characterization.

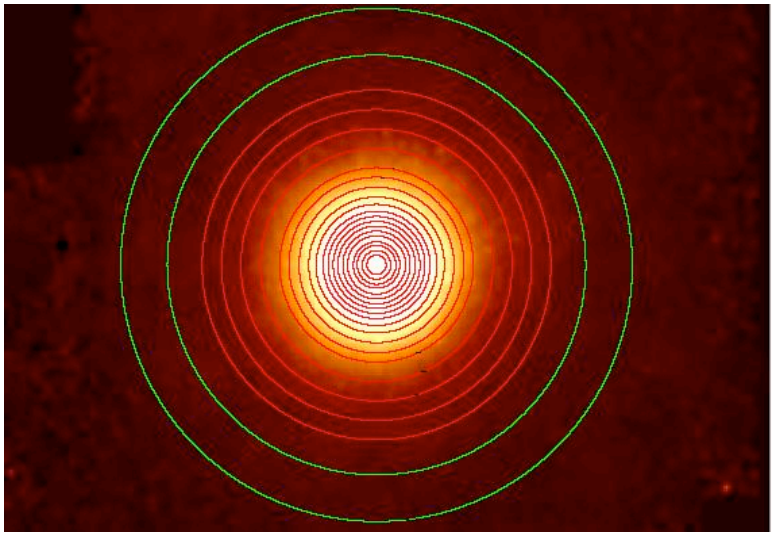
The WPRO extraction list is used as the input source list for WAPP. In this way every source extracted by WPRO using both passive and active deblending will have an aperture flux.

WAPP Flow


Data and mask frame stack; median-filtered backgrounds
Extraction list from profile-fitting
Extraction information: position, flux, σ_{flux}, χ^2, local background
For each frame, for each source
Locate masked or "bad" pixels within maximum aperture radius
Masked pixel within RMIN of central position?
yes
Reject source – do not perform aperture photometry; this is needed to produce clean aperture-correction (curve of growth) photometry
no
Replace masked pixels with the 'maximum likely value' or with a simple bi-linear interpolation
Compute multi-aperture photometry

Aperture Photometry

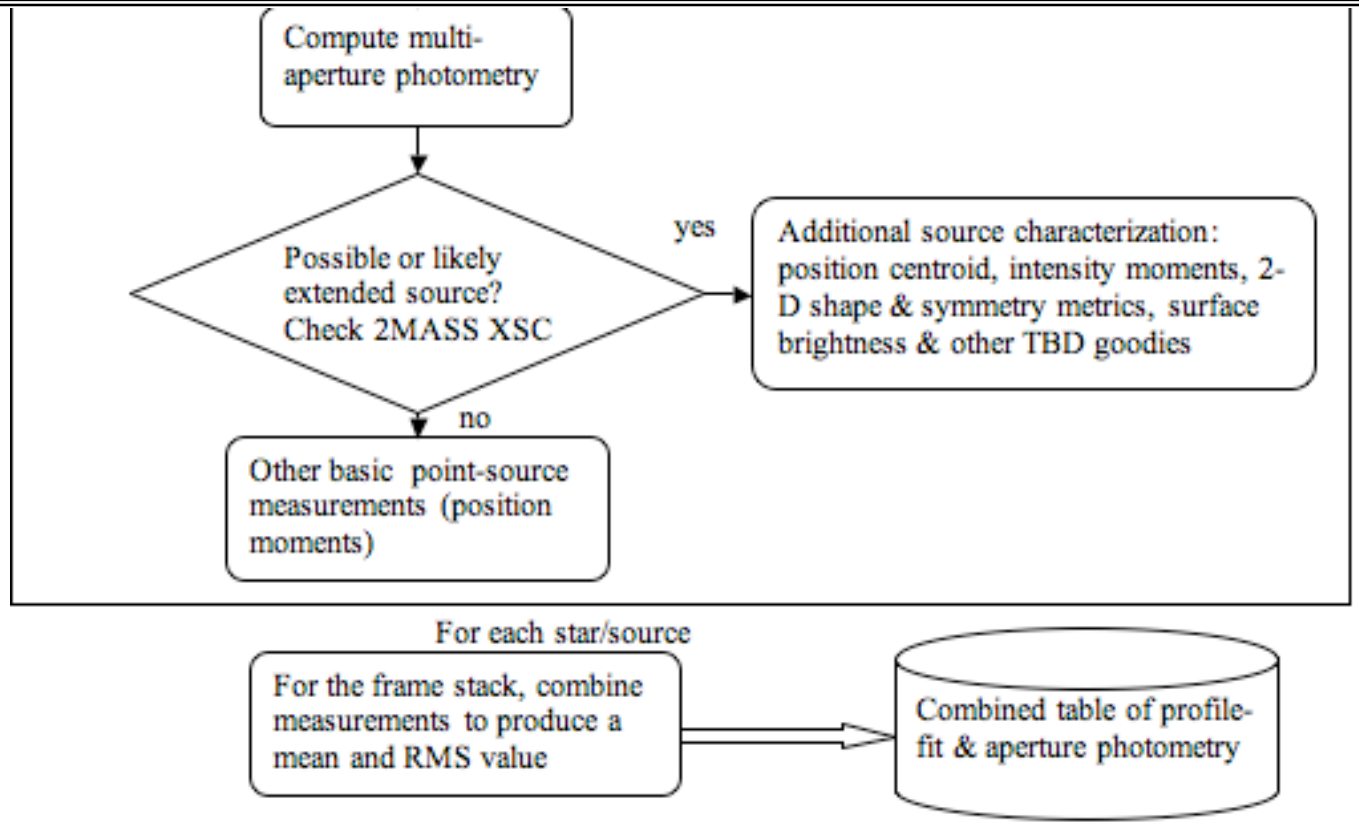




- *bad* pixels replaced with maximum likelihood values
- Local background annulus
- Nested apertures to capture curve-of-growth
- Stellar confusion?

- Nested apertures to capture extended source emission
- Integrated flux and source characterization limited by local background annulus size

WAPP Flow


Compute multi-aperture photometry
Possible or likely extended source? Check 2MASS XSC
yes
Additional source characterization: position centroid, intensity moments, 2-D shape & symmetry metrics, surface brightness & other TBD goodies
no
Other basic point-source measurements (position moments)
For each star/source
For the frame stack, combine measurements to produce a mean and RMS value
Combined table of profile-fit & aperture photometry

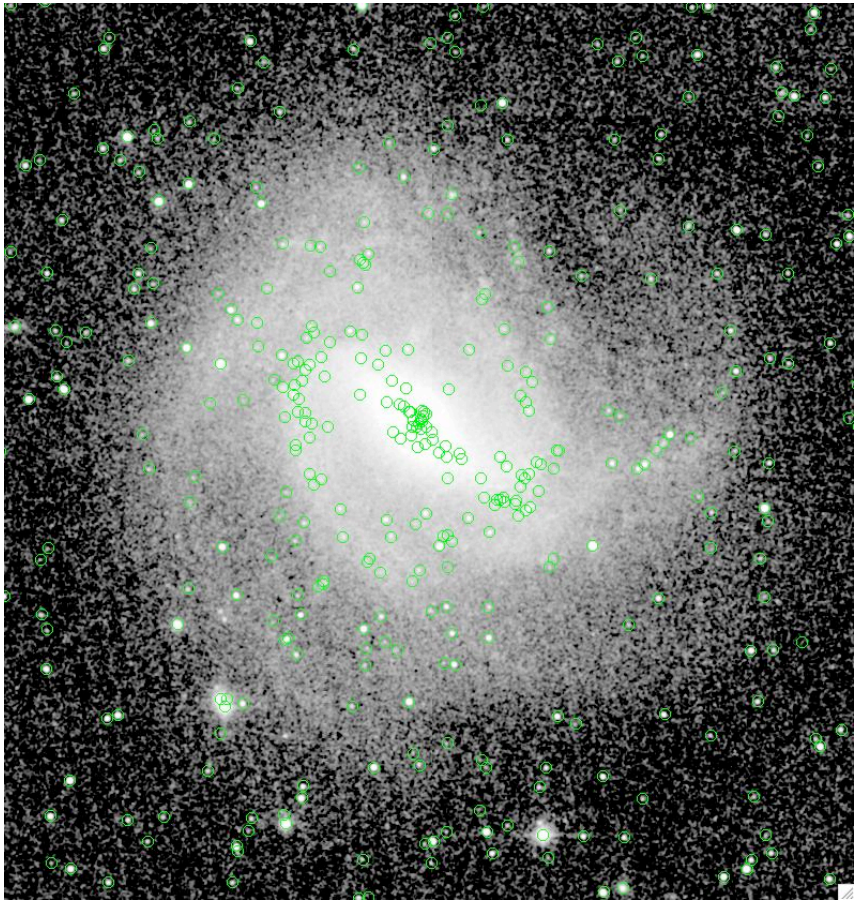
Extended Sources

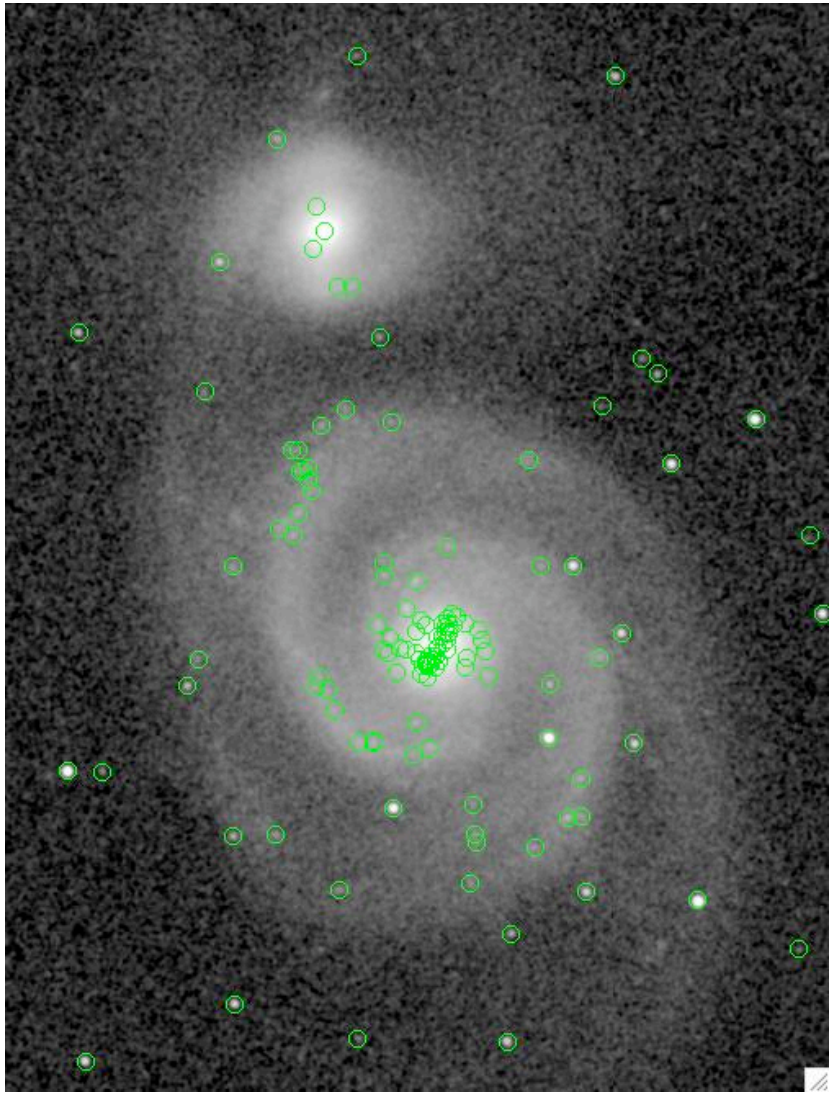
Impact & Implications

The source detection and photometry requirements only pertain to point sources

- Extended sources, in the form of fuzzy galaxies and Galactic nebulosity, will be present in every WISE image frame thus complicating the primary mission goal of detecting, characterizing and cataloging point sources.

Fuzzies Complicate Point Source Extraction





Without even minimal characterization of the extended source, we have no way of reliably flagging "point" sources that might be contaminated or modified by the underlying emission. At the very least we will need to flag sources that are in close proximity to 2MASS galaxies.

Identification & Measurement of Extended Sources

The basic data reduction must include some level of extended source characterization to properly handle point source photometry and quality assessment of the resulting catalogue.

A secondary issue is the scientific potential of the extended sources themselves. WISE will resolve hundreds of thousands of galaxies and its images will contain a rich assortment of Galactic emission, both high surface brightness and diffuse varieties.

Basic Measurements of Discrete Sources

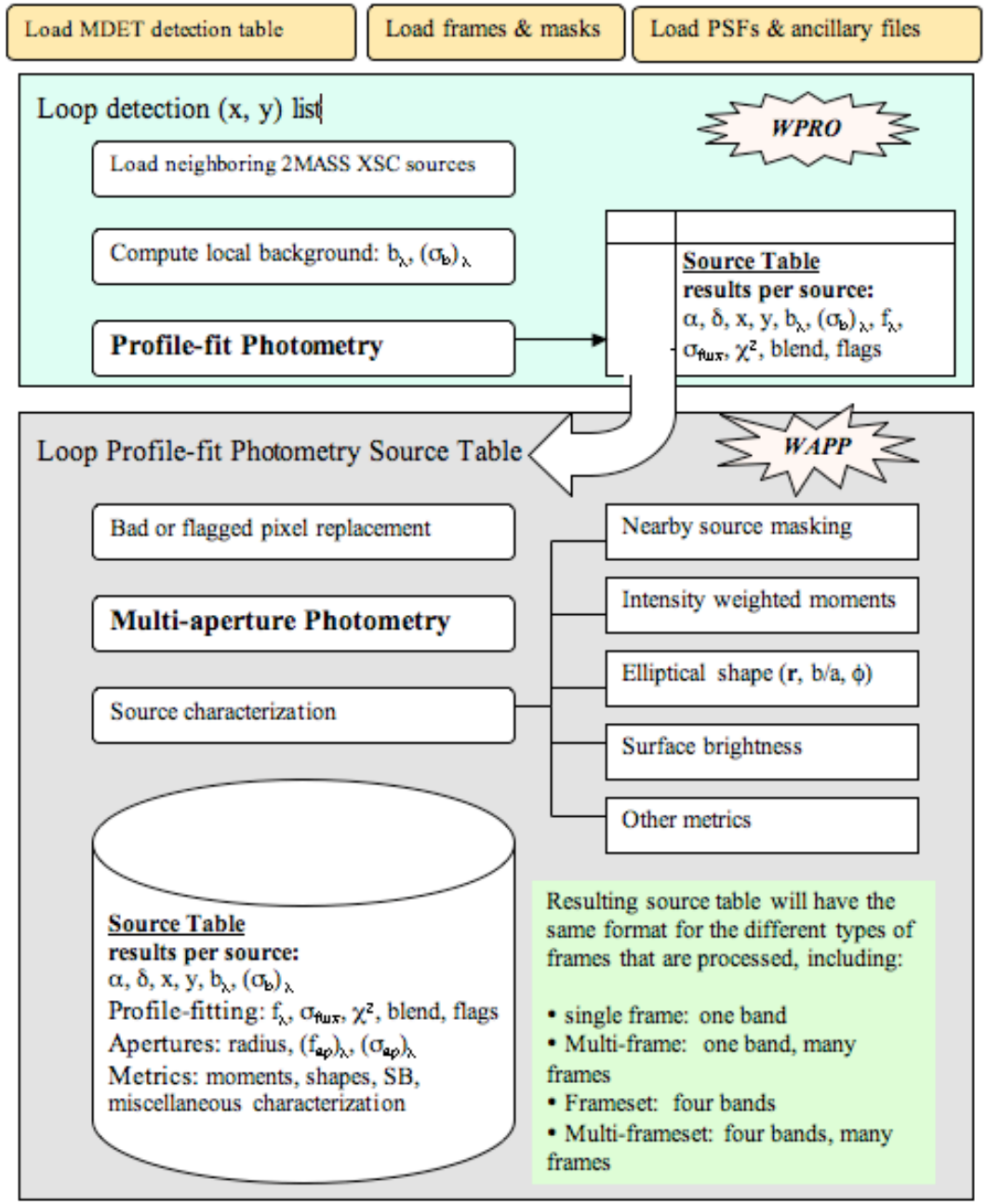
- Detection
- local background
- integrated flux(s)
- extent metric
- quality status

Harder to do:

- Star subtraction
- Shape
- blending

WPHOT *High-level Routines*

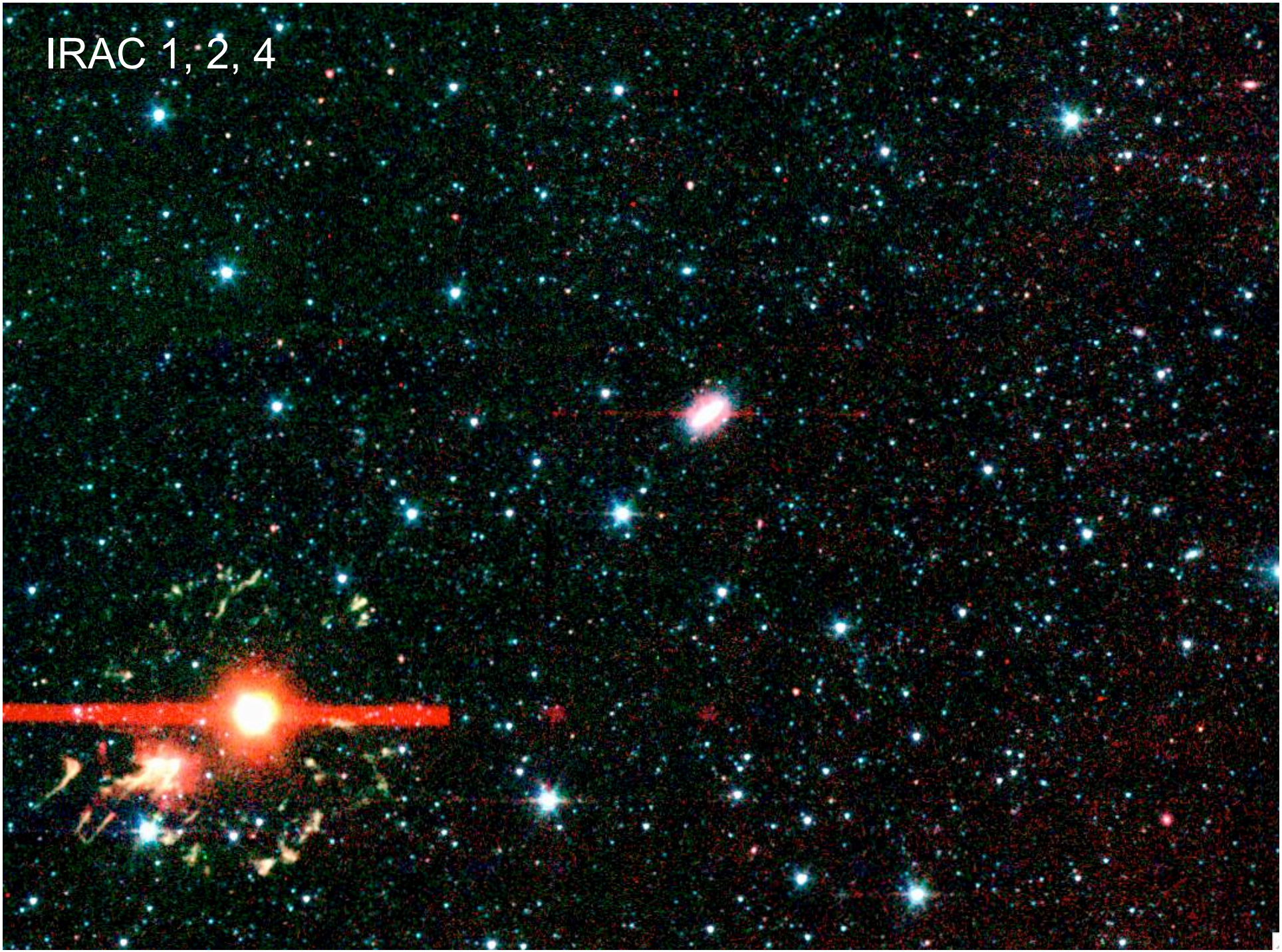
Inputs: Parameter list, source detection data, image data & ancillary information



Test Plan

Test Data Sets: NEP/SEP mini-surveys; SWIRE; WISE image simulations

- Integrity & Robustness of the algorithms
- Reliability (requirements)
- Completeness (MDET & WPRO); requirements
- Memory limitations
- Speed limitations
- Pipeline integration


IRAC 1, 2, 4

WAPP Annulus/Aperture testing

- Local background statistics; pixel-value histogram statistics.
- Small apertures, to test the fractional-pixel algorithm.
- Large apertures, to test the integrity of the system.
- Full range in fluxes, from noise to bright-saturated stars.
- Requirements (C & R)

Test Plan

WPRO testing:

- Validity of noise model: plots of χ_ν^2 vs. magnitude
- Validity of quoted errors: repeatability tests based on multiple observations (e.g., Spitzer observations of NEP)
- Active deblending tests:
  - -- Verify performance (completeness and reliability as a function of SNR, recovery of sources missed during detection step)
  - -- Determine optimal values of deblending parameters
- Response to artifacts and extended sources:
  - -- Saturated stars, diffraction spikes, latent images, etc.
  - -- Effectiveness of χ_ν^2 as discriminator

Development Schedule

- Peer Review (Feb ??, 2008)
- v0 2/27/08 prototype (single frame, multi-band), data flow testing
  - Input frames, masks & detection lists
  - Local backgrounds (stats)
  - Profile-fitting (isolated sources, multiband)
  - Aperture fluxes
  - Output table
- v1 6/19/08 payload ground testing
  - Input median-filtered background images
  - Profile-fitting (active and passive deblending, isoplanatic PSF)
  - Source Characterization
  - Full output table

Issues/Concerns

- Parameter tuning
- Extended Sources
- Very Bright Stars

Extra Slides

Extended Sources

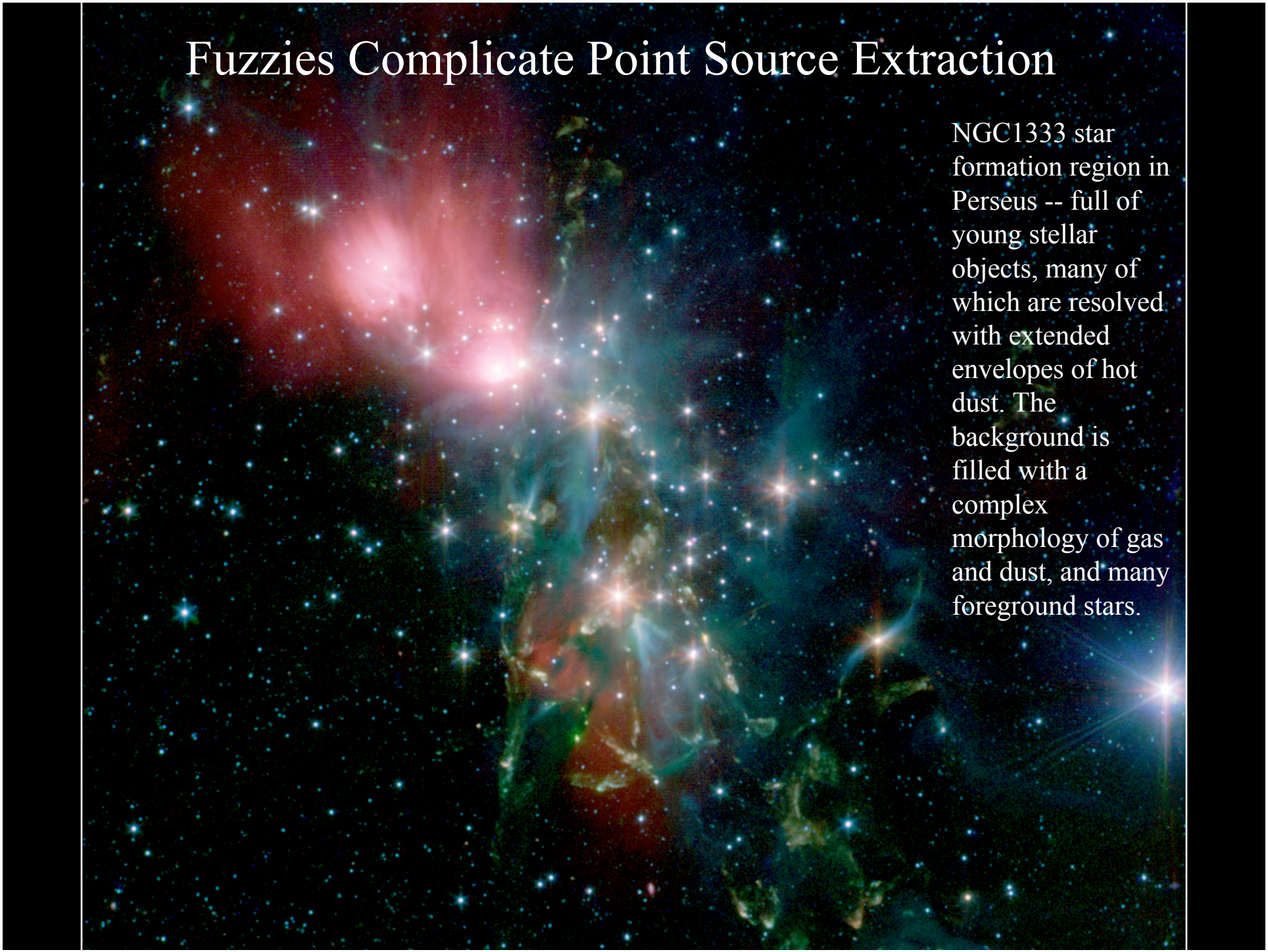
The source detection and photometry requirements only pertain to point sources

* Primary-- Do we attempt to identify extended sources and (potentially) improve the point source photometry that is affected/contaminated by the extended emission?

* Secondary-- Do we produce (and validate) images that have calibrated diffuse/extended emission? That is to say, is every pixel, whether it filled with Zody, or cirrus, or a piece of a galaxy have a calibrated surface brightness?

* Secondary--Do we attempt to detect and characterize discrete extended sources (e.g., galaxies) ? Do we add these measurements into the WISE source catalog(s) ?

Fuzzies Complicate Point Source Extraction

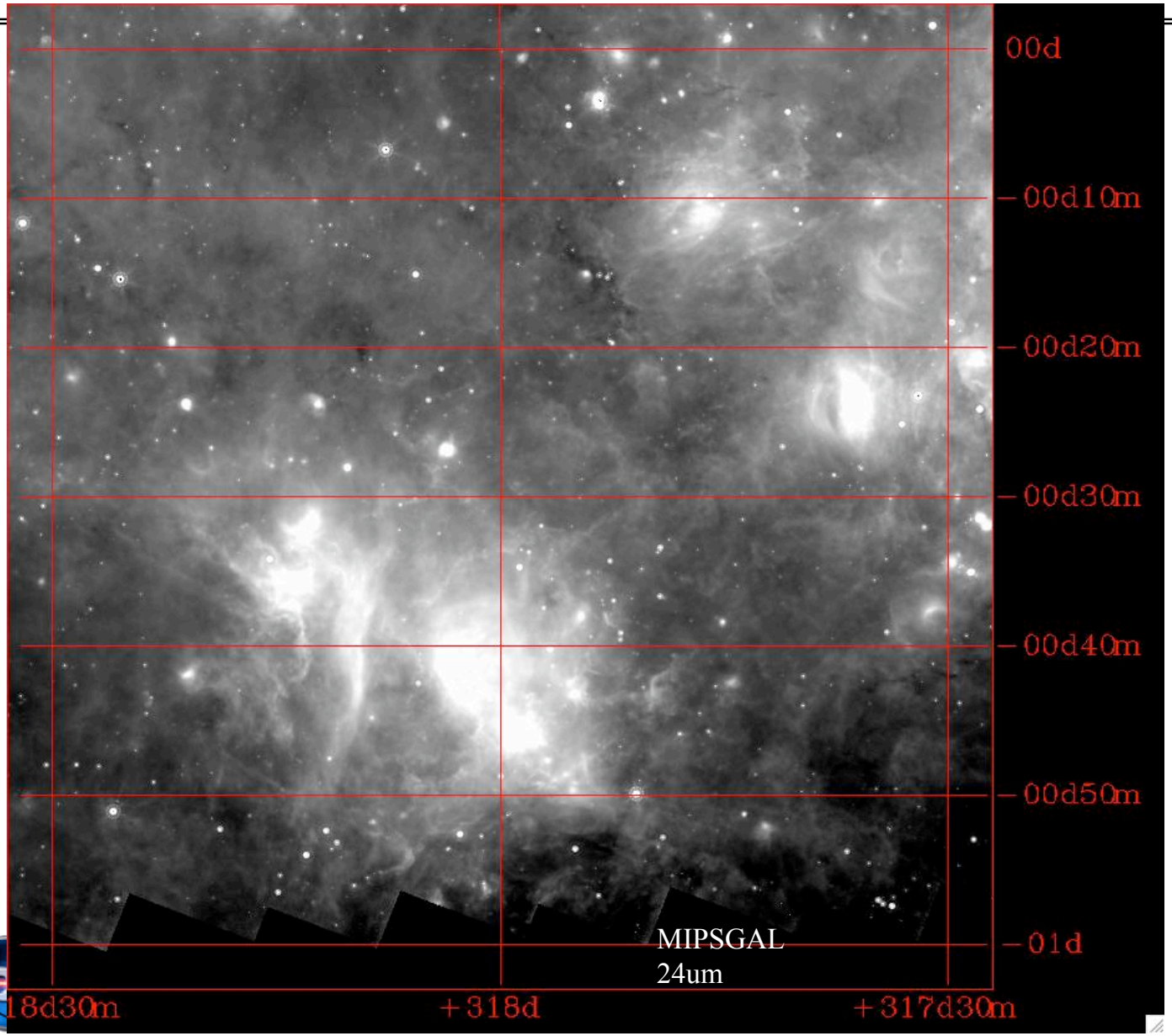


NGC1333 star formation region in Perseus -- full of young stellar objects, many of which are resolved with extended envelopes of hot dust. The background is filled with a complex morphology of gas and dust, and many foreground stars.

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

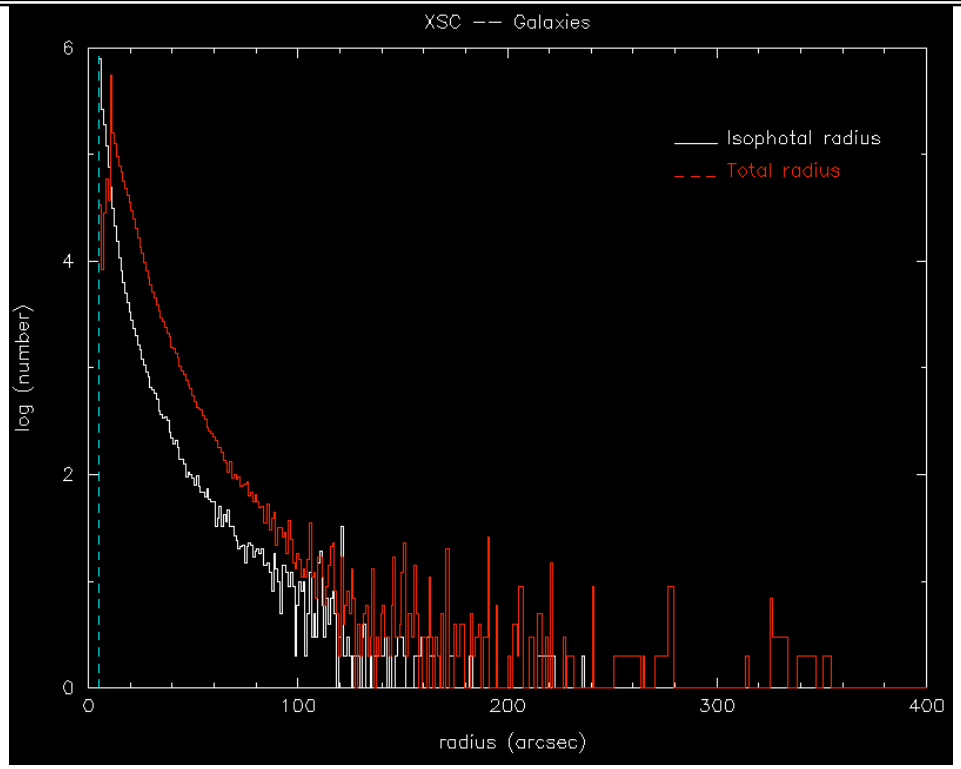
Milky Way

WISE
WPHOT



How do we flux calibrate this diffuse emission?

Resolved Galaxies



Based on the 2MASS Extended Source Catalog (XSC), we can expect tens of thousands of discrete sources (galaxies) to be resolved with WISE, at least at the short wavelengths.

D > 20″, N ~ 200,000 galaxies

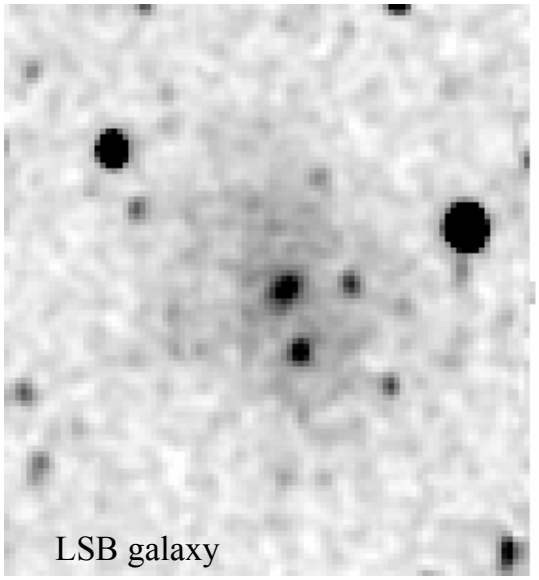
D > 40-50″, N ~ 20,000 galaxies

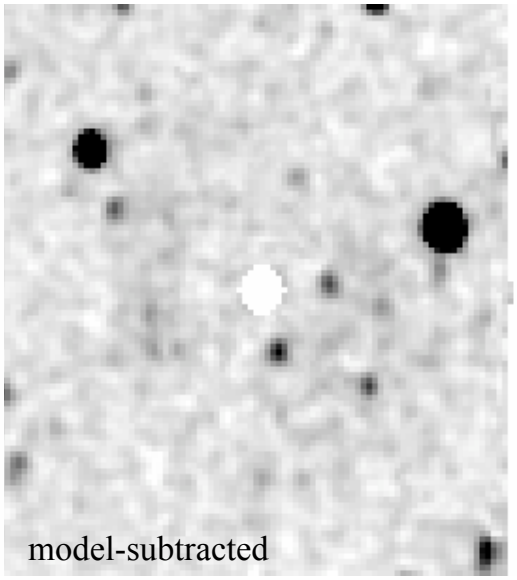
WISE will resolve <u>more</u> sources than this K-band estimate because of the disk-extended nature of the hot dust component (e.g., see the image of the Sombrero Galaxy. *Resolved sources must be treated more carefully to avoid systematic biases in the source catalog fluxes.*

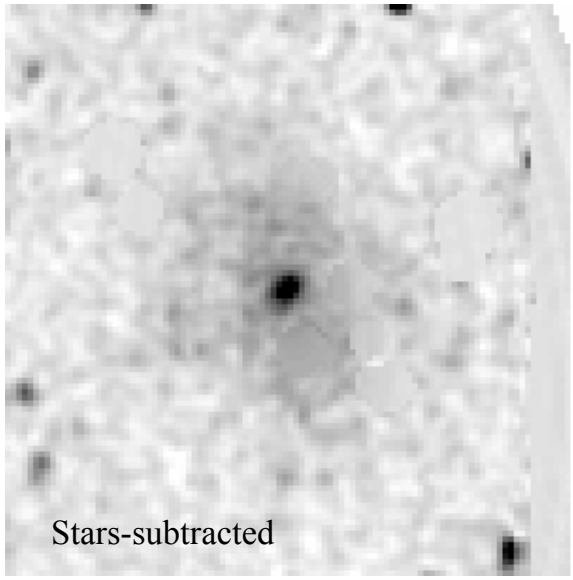
Advanced Measurements

* shape characterization (moments, ellipsoid model)
* star subtraction
* integrated flux with elliptical apertures
* surface brightness profiles
* size metrics
* total flux and SB measurements
* half-light and concentration indexes
* de-blend from nearby extended sources

High-end Characterization


LSB galaxy


model-subtracted


Stars-subtracted

- Shape Characterization (moments; ellipsoid model)
- Star subtraction / deblend
- SB profile
- Total flux & extent
- Half-light metrics
- Concentration index
- Plethora of isophotal & fixed aperture photometry

Further Considerations

* What do we do about point source measurements that are contaminated by the underlying extended emission?

* To detect extended sources, will the standard point source detector be good enough? For 2MASS we used the same detector to find stars and galaxies, but fuzzies were then processed separately from point-like sources, thus creating two separate catalogues in the end.

* Alternatively, we do not attempt to detect extended source, but instead we use a prior list (e.g., 2MASS XSC & the MSX catalog) to locate and measure extended sources. We use prior measurements (e.g., 2MASS has a full set) to aide in the WISE characterization, thus easing the development resources.

* Do we add extended source measurements to the WISE source catalog? Do we create requirements (at least internally) for a catalogue, or just do a "best effort" and flag the sources accordingly in the WISE catalogue?

* How far do we carry the source characterization beyond simple aperture fluxes? Using a prior list (see above), we may be able to push harder with minimal development.

* Given the mind-boggling confusion and source complexity in the Plane, do we avoid it altogether for extended sources? For 2MASS, we worked in the Plane, but significantly ramped down our expectations (sensitivity-throttled by the confusion noise).

* How much are we willing to dedicate to extended source characterization? How much to diffuse measurements? To image cleaning?